MIT Technology Review

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(REALLY) CREATIVE DESTRUCTION

Ben Milne wants to demolish the credit card industry and transform how we'll pay for everything.

Meet him and 34 other world-changing **innovators under the age of 35.**

10

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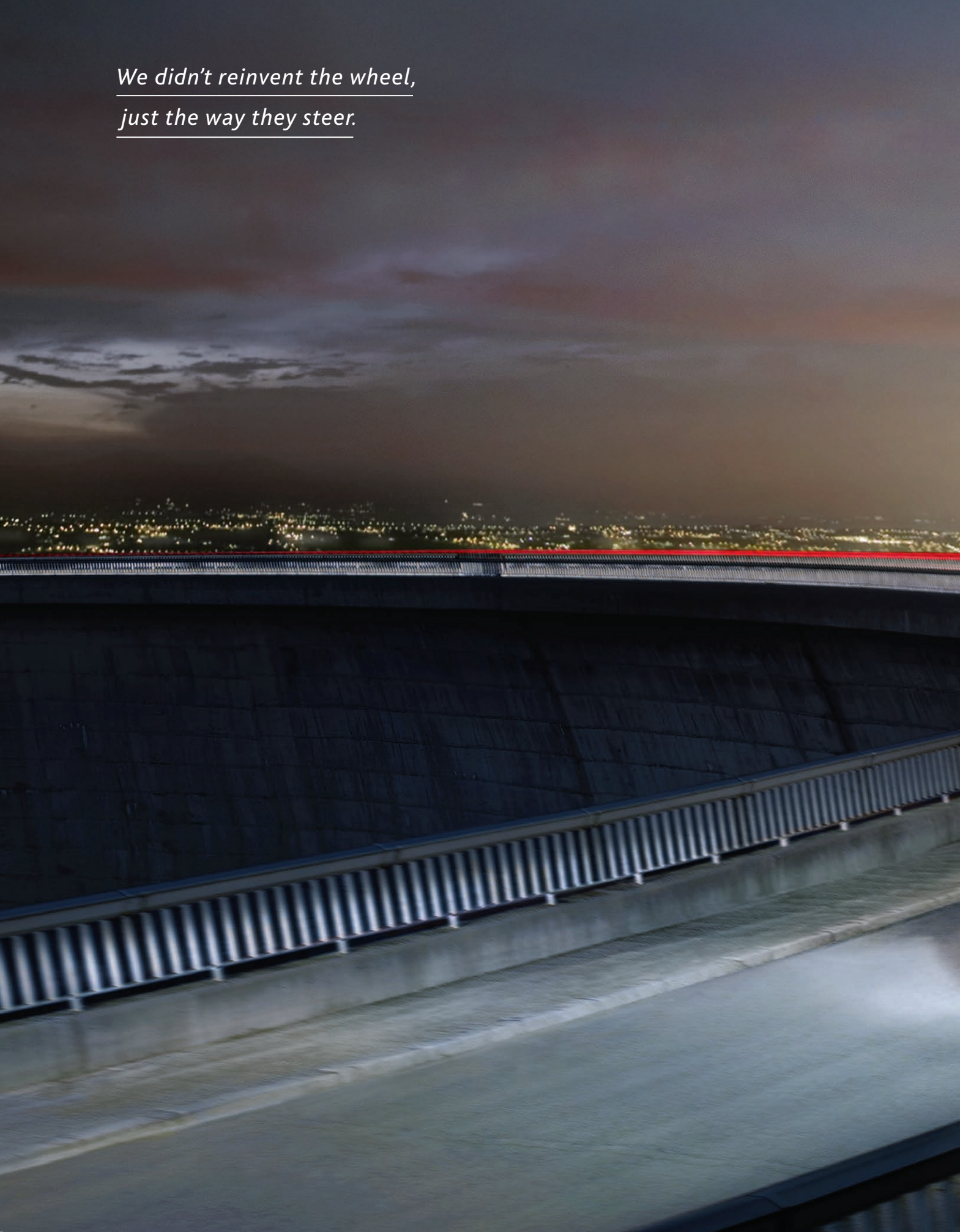
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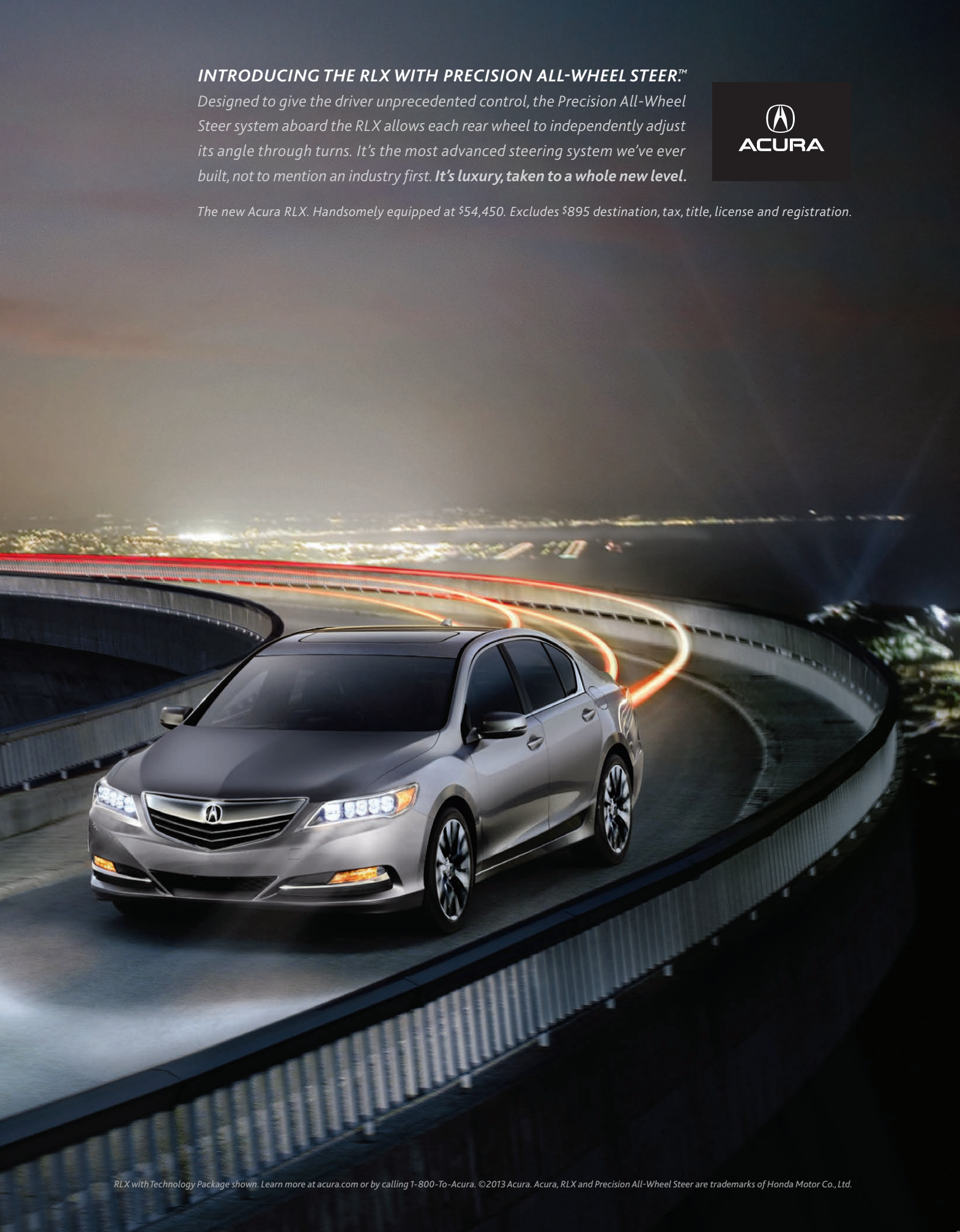
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From the Editor

Seven over 70

For over a decade, we've celebrated innovators under the age of 35. We choose to write about the young because we want to introduce you to the most promising new technologists, researchers, and entrepreneurs. But I often hear: You really think older people can't innovate?

Of course they can. We meet extraordinary older innovators all the time, who after a lifetime of creativity are still solving big problems, generating wealth, or expanding our conception of what it means to be human. Below, in reverse alphabetical order, are seven innovators over the age of 70, chosen arbitrarily, because I am attracted to their lives, work, and character, and not according to the formal nomination and judging process that selected the 35 Innovators Under 35 (see page 26).

George Whitesides, 74, is a cofounder of more than 12 companies (including Genzyme) whose combined value is more than $20 billion, and is named on more than 50 patents. Amongst his inventions are cheap paper microfluidic chips, which can be used for diagnostic tests in the poor world. At Harvard, he runs one of the world's most productive chemistry and materials science labs, whose objective is "to fundamentally change the paradigms of science."

The electrical engineer **Carver Mead**, 79, has been responsible for an implausibly long list of innovations in microelectronics, including the first software compilation of a silicon chip. Halfway through his career, he switched his research to how animal brains compute, and established the field of neural networks. After cofounding more than 20 companies, he is only notionally retired; today, he is thinking about better ways to teach freshman physics at Caltech, where he has worked for more than 40 years, by means of a "reconceptualization of electrodynamics and gravitation."

Barbara Liskov has been awarded both the Turing Award for her work on the programming languages and methodology that led to object-oriented programming and the John von Neumann Medal for her contributions to programming and distributed computing. At 73, she leads MIT's Programming Methodology Group, which is exploring how to build distributed and fault-tolerant systems that continue to work even when some of their components don't.

The physician and biologist **Leroy Hood** helped create the fields of genomics and proteomics by inventing the protein sequencer, the protein synthesizer, the DNA synthesizer, and, most important of all, the automated DNA sequencer. He later founded the Institute of Systems Biology in Seattle and, at 74, is still its president; the institute seeks to understand diseases by considering human biology holistically as a "network of networks."

Nick Holonyak invented the first practical light-emitting diode in 1962 when he was a researcher at General Electric, but his innovations are not limited to the replacement for the incandescent lightbulb. He also created the electronic element of the light dimmer switch and the laser diode, which is used in DVD players and cell phones. Holonyak, 84, is still a full-time researcher at the University of Illinois, where he works on quantum-dot lasers, which could be used for a variety of novel display and medical technologies.

The nanotechnologist **Mildred Dresselhaus**, 82, was the author of 39 papers in 2012 and most days is in her office at MIT by 6:30 A.M. Her research involves the physics and properties of carbon nanomaterials, including nanotubes and graphene. Among her many accomplishments, Dresselhaus was the first scientist to exploit the thermoelectric effect at the nanoscale, which could allow for devices that harvest energy from temperature differences in materials that conduct electricity.

Stewart Brand's contributions to technology have been as an intellectual and founder of organizations, rather than as an inventor. But Stewart (who is a friend) has been tremendously influential: he was the publisher of *The Whole Earth Catalog*; cofounded the first electronic community, the WELL; and is today the president of the Long Now Foundation, which promotes "slower/better thinking." At 74, he is working on the revival of extinct species.

I'll conclude this list with an extra name, from my own profession. Now 83, **Robert Silvers** has edited the *New York Review of Books* for more than 40 years. His is my favorite publication, because it is reliably surprising, delightful, witty, and humane. When asked why he doesn't retire, Silvers once joked, "I don't have a very full sense of time." He then more seriously added that work was an extraordinary opportunity, and that "you'd be crazy not to try to make the most of it."

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Feedback

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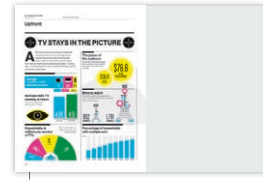

1

How Technology Is Destroying Jobs

I'm 49 and work in a car factory. We're increasingly becoming automated, and I see two consequences: less need for human workers and fewer consumers to buy the products. Those consequences will lead to some type of economic collapse if they're not corrected – the magnitude of change is beyond the ability of our government and financial institutions to survive. The corporate need for ever-increasing profit will accelerate the use of robotics. I believe this is inevitable and unstoppable. Sounds like a good plot for some hard-core science fiction. **– Geoff S. Jones, Bennington, Vermont**

2

The World as Free-Fire Zone

The thrust of Fred Kaplan's article "The World as Free-Fire Zone" is ill-conceived and absurdly biased. Would the author rather we suffer the consequences of not eliminating key terrorists? Would the author volunteer to go in and do manned missions instead? Colin Powell and many others have said what a majority of Americans would agree with – the U.S. does not want a "fair" war. The U.S. wants an unfair advantage, and if the author or any of his friends or family were in harm's way carrying out missions, they would surely agree. **– Rick Bridges, Dublin, California**

3

TV Stays in the Picture

This is a nice infographic, but it lacks the thoughtful dynamic of online video as a "TV" channel. Increasingly, platforms like YouTube are viable media channels for professionally produced content. And people increasingly view Web-based media via their Web-connected TVs. Some demographics view more content on mobile devices than they do on their TVs. Figures like number of channels or number of TVs are interesting, but they're not insightful. Still, the point is valid: TV is huge – but TV as we know it is changing dramatically. **– kevinrfoote**

4

Thad Starner: Google Glass's Mastermind

The privacy angle will probably give way to the legal realities of our sue-happy culture. How many high-profile legal battles would have been sorted out in days if a few of the primary people involved had video recordings of their actions? Already juries are discovering how terrible eyewitness testimony is. California's highest court has ruled the public now has a right to videotape the police for its own records and defense. The real value in savings of legal costs is going to be more compelling than notions of privacy. **– Sanescience**

5

The Secret to a Video-Game Phenomenon

My daughter does two things simultaneously: she watches YouTube videos, and she plays Minecraft in creator mode, designing the worlds she sees in her mind. The YouTube I could fathom. Minecraft? I had to examine that one a bit: Minecraft is easy. It's simple. It's transparent. It's visually appealing, in a grand, 10,000-foot kind of way. In the end it's creativity at its most primitive. While YouTube is a total mind suck, her Minecraft playing seems to even out the time-wasting aspect, making the two together rather a time-sink wash. **– anonymole**

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Letters and comments may be edited for both clarity and length.

Robots Aren't the Problem

The title of David Rotman's article, "How Technology Is Destroying Jobs," sums up the view of many who seek to explain lackluster U.S. job growth. But technology has never destroyed jobs on a net basis and it won't in the future. The article focuses on MIT scholars Erik Brynjolfsson and Andrew McAfee, who argue that workers are "losing the race against the machine, a fact reflected in today's employment statistics."

They make this claim in part because the historical relationship between productivity growth and job growth diverged after 2000. But there is no logical relationship between job growth and productivity. Two nations with the same productivity growth can have very different job growth depending on factors like fertility rates and immigration. Besides, if technology really is the cause of sluggish job growth, productivity growth should have been higher after 2008. But productivity grew only 1.8 percent per year from 2008 to 2012, compared with 2.6 percent per year from 2000 to 2008, when we had close to full employment.

Brynjolfsson and McAfee consider the first-order effects of a machine replacing the worker. But there is a second-order effect: the organization using the machine saves money, and that flows into the economy through lower prices, higher wages, or higher profits. And that stimulates demand that other companies meet by hiring more workers. This is why virtually all economic studies looking at the relationship between productivity and jobs find either no or positive impacts on total jobs in the moderate term.

Some will argue that this time it's different. As Rotman states, "Technologies like the Web, artificial intelligence, big data … are automating many routine tasks." But this assumes that productivity growth rates will increase significantly, and there's little evidence for this. A growing share of jobs involve tasks that are difficult to automate (e.g., in nursing homes or construction).

The worries that machines are displacing workers are as old as machines themselves. As my coauthor Stephen J. Ezell and I argue in *Innovation Economics: The Race for Global Advantage*, far from being doomed by an excess of technology, we are actually at risk of being held back by too little technology.

Robert D. Atkinson is the president of the Information Technology & Innovation Foundation, a think tank based in Washington, D.C.

Views

Ashkan Soltani

David G. Victor

Robert Nussbaum

COMPUTING

Soaring Surveillance

Technical, not legal, constraints determine the scope of U.S. government surveillance, says Ashkan Soltani.

Recent revelations about the extent of surveillance by the U.S. National Security Agency come as no surprise to those with a technical background in the workings of digital communications. Dramatically expanded, highly efficient surveillance programs are predictable given the increased use of digital communication and cloud services—and America's outdated privacy laws. Our national discussion must take into account the extent to which technology has made surveillance easier and cheaper than ever before.

The American people, maybe unknowingly, relied for years on technical and financial barriers to protect them from large-scale surveillance by the government. These implicit protections have quickly eroded in recent years as digital communication technology has spread through society and advances pioneered in the technology industry have reached intelligence agencies. As a result, we now have to replace these "natural" boundaries and revise the law to protect our privacy.

Spying no longer requires planting bugs.

Ashkan Soltani

The majority of our communications are now delivered and stored by third-party services and cloud providers. The bulk of e-mails, documents, phone calls, and chats go through a handful of Internet companies such as Google, Facebook, and Skype or wireless carriers like Verizon, AT&T, and Sprint. And while it's distributed in nature, the physical infrastructure underlying the World Wide Web relies on key chokepoints that the government can, and does, monitor. The NSA needs to establish relationships with only a few critical companies to capture the majority of the market it wants to observe. With very little effort or cost, it can observe hundreds of millions of people communicating over these services.

Each of the NSA programs recently disclosed by the media is unique in the type of data it accesses, but all of them have been made possible by the same trend: surveillance techniques have been exploding in capacity and plummeting in cost. One leaked document shows that between 2002 and 2006, it cost the NSA only about $140 million to gather phone records for 300 million Americans, operate a system that collects e-mails and other content from Internet companies such as Google, and develop new "offensive" surveillance tools for use overseas. That's a minuscule portion of the NSA's $10 billion annual budget.

Spying no longer requires following people or planting bugs; rather, it means filling out forms to demand access to an existing trove of information. The NSA doesn't bear the cost of collecting or storing data and no longer has to interact with its targets. The reach of its new programs is vast, especially when compared with the closest equivalent possible just 10 years ago.

What we have learned about the NSA's capabilities suggests it has adopted a style of programmatic, automated surveillance previously precluded by the limitations of scale, cost, and computing speed. This is a trend with a firm lower bound. Once the cost of surveillance reaches zero, we will be left with our outdated laws as the only

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Views

protection. Whatever policy actions are taken to regulate surveillance in light of the recent leaks should recognize that technical barriers offer dwindling protection from unwarranted government surveillance at home and abroad.

Ashkan Soltani is an independent researcher who previously investigated online privacy issues as a staff technologist with the U.S. Federal Trade Commission.

ENERGY

Climate Diplomacy

President Obama must focus on getting other nations to cut their emissions, says David G. Victor.

In June, President Obama broke several years of near silence on how the United States would address climate change. That he did so is notable, but the new plan is mostly the same as the old plan, centered on promoting efficiency and cleaner technologies. Practically nobody is talking about the most important test for Obama's climate strategy: how it will affect the strategies of other nations.

In 1990, when global warming first rose to prominence as an international issue, the United States could unilaterally set the tone for the world. America was undisputed leader of the global economy and the world's biggest polluter. Since then, the U.S. share of all gas emissions that cause global warming has dropped from 16 percent to 13 percent. U.S. emissions are now falling, while those from most of the rest of the world, notably China, grow rapidly. Today the global problem is much harder for the U.S. to manage just by changing its policies at home.

Obama's plan could signal a fresh start.

David G. Victor

The key question for President Obama is whether his new policy can have any impact on other countries. So far, the answer is probably no. U.S. credibility has suffered from the perception that this country is good at criticizing schemes to cut global emissions, such as the Kyoto Protocol, but not very talented at creating alternatives that actually work.

Other countries now understand that political gridlock in Washington makes it hard for American diplomats to promise them anything like backing for a global treaty to cut emissions. It is telling that the new climate plan outlined by President Obama relied mainly on regulatory and funding actions he can take alone, rather than new legislation that would require help from Congress.

There are signs that this strategy might have an effect. In recent months the Obama administration has created new programs with China to study and test low-emission energy technologies. In June the leaders of the two countries agreed to help phase out hydrofluorocarbons, potent global-warming gases used in refrigeration and cooling systems.

The United States is now likely to find it more effective to work with countries individually or in small groups than to focus on large global forums. Smaller forums make it easier to achieve action, and to help other countries find practical ways to coöperate.

Closer to home, the debate over the Keystone XL pipeline that would move crude from Canadian oil sands through the United States may provide the first definite success for that strategy. The pipeline's fate is in U.S. hands, and although without it, the oil could still travel by alternate routes that bypass the U.S., stalling approval could force the Canadians to promise their own more credible program to cut emissions.

Because emissions anywhere affect the whole planet, every plan, whether conceived by the smallest city or the biggest nation, should be judged by whether it advances the global agenda. On that score, Obama's new climate plan could signal a fresh start—if it gives the U.S. more practical leverage over the actions of other countries as well as our own.

David G. Victor is a professor at the School of International Relations and Pacific Studies at the University of California, San Diego.

HEALTH

Corporate Genetics

Even without gene patents, companies are monopolizing genetic data, says Robert Nussbaum.

In June the U.S. Supreme Court ruled that patents on genes were invalid. Yet corporate intellectual-property claims can still harm patients.

The court struck down patents held by Myriad Genetics on two human genes linked to breast and ovarian cancers, BRCA1 and BRCA2. The decision ended the company's U.S. monopoly on testing those two genes for cancer-related mutations. But Myriad is now using a different tactic that restricts patient choice around genetic testing. The company has constructed a database of the genetic variants found in people who took its BRCA test. That unparalleled record of the natural variation in these important genes—collected from patients—is claimed to be Myriad's own intellectual property.

Doctors can't assess the significance of gene variants they find in their patients without free exchange of the kind of information held in Myriad's database. It is as if patients' radiological images were all examined by a single company

that didn't give the medical community a chance to learn from them.

Myriad's database prevents patients from easily getting second opinions when they receive diagnoses based on BRCA tests. Patients need to be able to seek confirmation that the gene variant they have really does mean what the testing laboratory says it means. That can't happen if Myriad is the only one with the data.

Late last year, I launched a grassroots effort bringing doctors and patients together to free valuable data from BRCA1 and BRCA2 test reports. Colleagues of mine who see patients at cancer clinics now place copies of these reports—with identifying details removed—in an existing public database called ClinVar, which is run by the National Institutes of Health. This project, called Sharing Clinical Reports, has now made more than 6,000 reports accessible. Efforts to enlist coöperation from clinics around the country should free up tens of thousands more reports soon.

The medical community has condemned private databases that limit the dissemination of medical knowledge. The American Medical Association adopted a resolution in 2009 stating: "The use of patents, trade secrets, confidentiality agreements, or other means to limit the availability of medical procedures places significant limitation on the dissemination of medical knowledge, and is therefore unethical." A newer resolution, in June, calls for the release of all information generated by testing for genetic variants, with appropriate privacy protections. We're still far from seeing that come to pass. The medical community must prevent intellectual-property claims from being used to monopolize such vital data.

Robert Nussbaum is chief of the Division of Genomic Medicine at the University of California, San Francisco, and worked on the legal challenge to Myriad's gene patents.

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Upfront

The Immortal Life of the Enron E-mails

Years after the company imploded in scandal, its e-mails still help advance data science and other fields.

By Jessica Leber

Vincent Kaminski is a modest semi-retired business school professor from Houston who recently wrote a 960-page book explaining the fundamentals of energy markets. His most lasting legacy, however, may involve thousands of e-mails he wrote more than a decade ago at Enron.

Kaminski, a former managing director for research who warned repeatedly about troubling practices at the energy-trading company, is among more than 150 senior executives whose e-mail boxes were dumped onto the Internet by the Federal Energy Regulatory Commission (FERC) in 2003. In the name of serving the public's interest during its investigation of the company, the federal agency posted more than 1.6 million e-mails that Enron executives sent and received from 2000 through 2002. FERC eventually culled the trove to remove the most sensitive and personal data, after receiving complaints. Even so, the "Enron e-mail corpus," as the cleaned-up version is now known, remains the largest public-domain database of real e-mails in the world—by far.

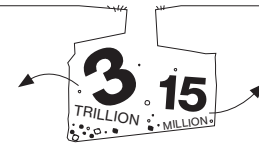
This corpus is valuable to computer scientists and social-network theorists in ways that the e-mails' authors and recipients never could have intended. Because it is a rich example of how real people in a real organization use e-mail—full of mundane lunch plans, boring meeting notes, embarrassing flirtations that revealed at least one extramarital affair, and the damning missives that spelled out corruption—it has become the foundation of hundreds of research studies in fields as diverse as machine learning and workplace gender studies.

Computer scientists have used the corpus to train systems that automatically prioritize certain messages in an in-box and alert users that they may have forgotten about an important message. Other researchers use it to develop systems that automatically organize or summarize messages. Much of today's software for detecting fraud, combating terrorism, and mining workplace behavioral patterns over e-mail has been somehow shaped by the data set.

DANIEL ZENDER

Upfront

Metric tons of carbon dioxide that could be buried in the U.S. alone, according to geologists.



Metric tons of carbon dioxide that will be buried in the U.S. this year.

"It's like we are studying yeast," says William Cohen, a Carnegie Mellon University computer scientist who helped put the corpus in a database that could be mined by researchers. "It's studied and experimented on because it is a very well understood model organism. [The e-mail generated by] Enron is similar. People are going to keep using it for a long time."

The Enron e-mails were given their extended life by scientists at MIT, Carnegie Mellon University, and the nonprofit research institute SRI International. Ten years ago, these researchers were collaborating on the DARPA-funded CALO project, which stands for "Cognitive Assistant that Learns and Organizes," and whose biggest claim to fame is giving rise to Apple's Siri software. For CALO, the researchers were cobbling together much smaller e-mail data sets to analyze.

When the Enron e-mails were posted in 2003, the researchers realized that they could be extremely useful for testing algorithms that could process written language and form the basis of intelligent workplace tools. Because FERC had posted the e-mails in an unusable format, MIT's Leslie Kaelbling purchased the raw files from a government contractor for $10,000, and others spent time cleaning up the data—weeding out duplicates, organizing folders, taking out the remaining private e-mails and attachments, and mapping the senders and recipients to Enron's organizational structure. The corpus, at first more than 517,431 e-mails, was whittled down to 200,000 by 2004.

A research ecosystem still blooms around the corpus because there is nothing else like it in the public domain. If it didn't exist, research into business e-mails could be done only by people with access to big corporate or government servers. That probably would exclude social science, organizational, and linguistics researchers—many of whom have used the corpus to glean valuable insights into corporate culture, says Owen Rambow, a Columbia University professor involved in a research project that used the Enron corpus and received a $510,000 grant from the National Science Foundation.

Researchers who have worked with the corpus know there won't be another one like it.

Since 2010, about 30 papers a year have cited the original paper that presented the Enron corpus, Carnegie Mellon's Cohen estimates. This year, for instance, researchers at HP Labs turned to the corpus to demonstrate an artificial-intelligence program for automatically identifying the commitments people make over e-mail. Jafar Adibi, who worked on an early map of the Enron social network, says he still gets inquiries every month, more and more from researchers outside the United States.

Researchers who have worked with the corpus know there won't be another one like it. FERC released the e-mails back when the world still had a lot to learn about online privacy. The harms to people mentioned—most of whom were innocent of any wrongdoing at Enron—were quickly apparent. Social Security numbers and even bank records were in the files. Though much private data has been removed, browsing hundreds of e-mails in Kaminski's "sent" folder, I found a home phone number, his wife's name, and an unflattering opinion he held of a former colleague. At the time the e-mails were first released, Kaminski, the manager of about 50 employees at Enron, said he was most disturbed to see his back-and-forth communications about HR complaints and job candidates become public.

Today, many people who work in highly regulated industries like finance avoid putting sensitive information in their e-mails. Kaminski, who later served as a managing director at Citigroup, notes that the acronym "LTOL" became popular e-mail lingo in the years following Enron. It stands for "Let's take this offline."

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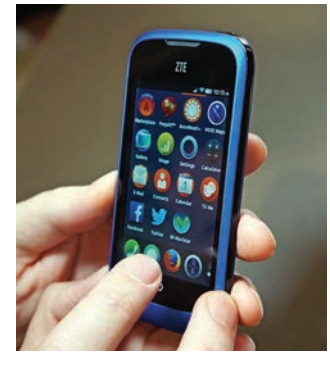
AVAILABILITY:
Now

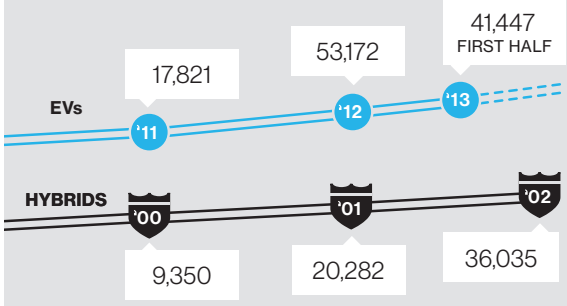
The nonprofit organization behind the Firefox Web browser hopes to make smartphones easier to use and less expensive. Phones with the free Firefox operating system break from the model that requires users to download lots of apps in advance; instead, the devices connect to relevant applications as they might be needed and run them in the cloud rather than on the phone. So if you use the phone's search function to look up a band, the device might simultaneously offer ways to listen to a stream of its songs, buy the songs, and buy concert tickets. The system is built on Web standards such as HTML5 so that it will appeal to developers without resources to make apps for multiple platforms.



RACHEL METZ/ MIT TECHNOLOGY REVIEW
OPPOSITE PAGE: ILLUSTRATION BY POST TYPOGRAPHY; DATA FROM U.S. DEPARTMENT OF ENERGY (EV1. EMISSIONS, HYBRID SALES), INTERNATIONAL ENERGY AGENCY (BATTERY DATA,EV STOCK), NISSAN (LEAF), HYBRID CARS.COM (EV SALES)

The Electric Car Is Here to Stay

Sales of new-wave electric vehicles in the first three years after their introduction in the U.S. exceeded the number of hybrids sold in their first three years. Last year, 435,000 hybrids were sold in the U.S., or 3 percent of the market.



GM EV1	1997	2013	NISSAN LEAF
LEAD-ACID	BATTERY CHEMISTRY		LITHIUM-ION
1,310 POUNDS	BATTERY PACK WEIGHT		606 POUNDS
18.7 KWH	BATTERY CAPACITY		24 KWH
55 TO 95 MILES	APPROXIMATE RANGE		75 MILES
$49,350 INFLATION ADJUSTED	PRICE		$28,800 BEFORE SUBSIDIES

TOP 5 COUNTRIES FOR EVs

These account for nearly 80 percent of the world's overall stock.

U.S.	JAPAN	FRANCE	CHINA	U.K.
71,174	44,727	20,000	11,573	8,183

1888 *German engineer Andreas Flocken builds what is widely considered the world's first four-wheeled electric car.*

1897 *Electric vehicles enter the New York City taxi fleet.*

1912 *Worldwide electric-vehicle stock reaches 30,000.*

1930s *Electric vehicles are made virtually obsolete by cheap gasoline for cars with internal-combustion engines.*

1996 *To meet California emission standards, General Motors produces and begins leasing the EV1.*

1997 *Toyota begins selling the Prius, the world's first commercial hybrid, in Japan.*

2010 *Nissan releases the all-electric Leaf.*

2011 *Global EV stock hits new peak of 50,000.*

2012 *Global EV stock passes 180,000.*

AVERAGE EMISSIONS PER MILE

Pounds of CO_2

- .87 INTERNAL COMBUSTION
- .62 PLUG-IN HYBRID
- .57 HYBRID
- .54 ALL-ELECTRIC

CHEAPER BATTERIES

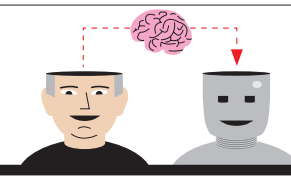
Some $8.7 billion in R&D spending by governments worldwide has helped to lower the cost of batteries. That means electric cars can cost less or have longer ranges for the same price.

2008	2012
$1,000 per kWh	$485 per kWh

"HYBRID" refers to vehicles that, like the Toyota Prius, combine an internal-combustion engine with one or more electric motors but do not draw electricity from the grid. "Electric vehicle" refers to both plug-in hybrids like the Chevrolet Volt and plug-in vehicles powered solely by a battery, like the Nissan Leaf.

Upfront

$3 million: Amount that Russian Internet entrepreneur Dmitry Itskov spent to create Global Future 2045, a gathering of so-called transhumanists who hope to download their minds into android bodies.



A Chip That Zeros In on Cancer

Technologies that can pull tumor cells from patients' blood are providing an unprecedented look at the disease.

By Susan Young

In the near future, oncologists may be using a finger-size plastic chip with tiny channels to extract a dozen or so cancer cells from a sample of a patient's blood. Those cells, called circulating tumor cells, could then be screened for genetic disruptions that an oncologist could target with drugs best suited to attacking the tumor. Continued sampling would give doctors a way to monitor whether a treatment is working and decide whether to add or change a drug as the malady evolves.

Dozens of companies are vying for success in this market, which is expected to reach $7.9 billion in the next few years. One device, sold by a Johnson & Johnson subsidiary, has received approval from the U.S. Food and Drug Administration, but it can't detect circulating tumor cells when they're present only in very small numbers, says Daniel Haber, director of the Massachusetts General Hospital Cancer Center. And today's device cannot capture the full diversity of cells that escape from tumors of different types.

The next generation of these chips, however, appears more promising. Advances have already been made in labs and may be making their way to clinics in the next few years.

Working with biomedical engineer Mehmet Toner and his team at MGH, Haber is developing a chip that can pull out any cancer cell that might be floating in the blood and keep it alive so pathologists can do genomic and molecular tests on it.

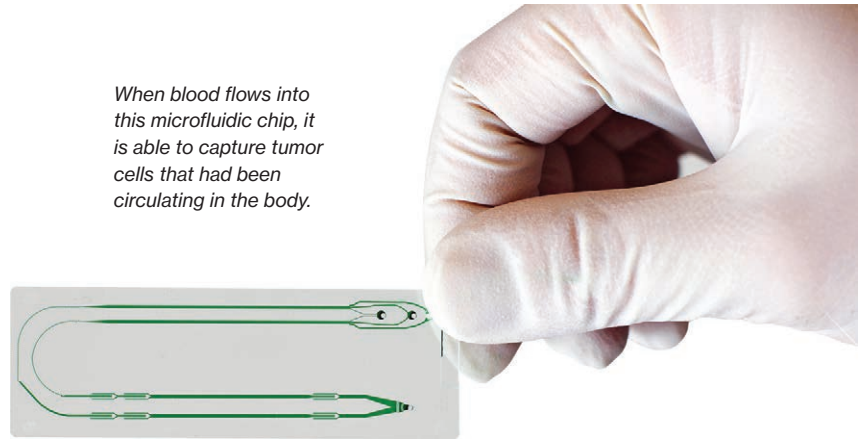
This could offer the ability not only to detect cancer earlier but also to monitor it over time. That's important because as a cancer grows and spreads in the body, it changes, with different genetic mutations showing up in the cells.

Overall, having more precise information about cancer cells will be increasingly valuable because pharmaceutical companies are developing cancer drugs with specific molecular targets in mind. These targeted therapies stand to substantially improve cancer treatment. The cancer genomics company Foundation Medicine says that as many as 70 percent of tumors it analyzes carry genetic signatures that can inform treatment.

Although the scientific and medical community has long known that cancer spreads through the bloodstream, there has been no way to capture the circulating tumor cells. "These are rare cells in the midst of 100 billion other cells," says Toner. The microfluidic chips offer "an opportunity to more precisely manipulate the blood and see if these cells are there in a useful number."

Johnson & Johnson has partnered with MGH to develop the new chip into a commercial product. Like some other devices in development, it isolates rare cancer cells by discarding all red blood cells and white blood cells, which typically outnumber circulating tumor cells by the billions. Any cancerous cells would then be left in a life-friendly liquid, from which they can be grabbed individually and studied.

Other versions of the technology, including the device that Johnson & Johnson currently sells, capture the cells on a physical surface, usually through a coating of antibodies that recognize proteins on the cell membranes of some, but not all, cancers.



When blood flows into this microfluidic chip, it is able to capture tumor cells that had been circulating in the body.

Beyond the potential to improve cancer treatment, devices that can capture circulating tumor cells could help biologists uncover the secrets of cancer's deadly spread.

"The question of how cancer metastasizes and spreads has never really been understood because we didn't have the tools to study it," says Haber. "This is the first time that you are looking at cancer cells in transit. They aren't there long, but they are there."

BERKIN CILINGIROGLU

OVH.COM

OVH.com, a hosting provider dedicated to securing data in the Cloud

Data and information security, a problem well known by companies with internal data centers, is an even more important issue for IT professionals facing the challenge to select an external private Cloud solution.

Indeed, hosting information, sensitive or not, at a third-party provider can raise doubts over the data actual confidentiality, security and integrity. To guarantee a maximum level of security to its clients, OVH.com followed a set of best practices to build its own Dedicated Cloud solution.

Secured data centers keep data safe

All the data on Dedicated Cloud are hosted on OVH.com's own data centers, and built to meet the Tier IV requirements. They are also designed and maintained by OVH.com. These buildings are real fortresses, with the highest levels of security and able to resist any physical intrusions. They are highly protected, equipped with a video-surveillance system, movement detectors and a next-generation fire suppression system. The OVH.com technical teams are on-site 24/7 to monitor the availability of resources and can reach the server rooms in just a few minutes: in case a server has any problem, it is quickly replaced.

A redundant infrastructure for a near-total availability

To guarantee an SLA (Service Level Agreement) of 99.99999%, OVH.com has set up emergency procedures to respond to any hardware failures. Every hardware equipment (storage, servers, hosts…) is fully redundant to reduce any risks of downtime. These equipments also include two separate power supplies and are connected to their own Uninterruptible Power Supply (UPS). Same thing for the network: each equipment is connected - using 2 separate ports - to two different switches, itself connected to 2 routers. The full redundancy of the infrastructure allows OVH.com to guarantee its Dedicated Cloud customers a near total availability of their resources, such as servers, storage or network. Therefore, the failure of an equipment has no impact on the infrastructure or the data availability.

A focus on data backup

Because backing up the data stored in the Cloud is critical, Dedicated Cloud backup solutions are RAID-10, at the least, offering an excellent level of protection. The same file is written simultaneously on at least two separate disks, protecting the user's data in the rare case of a disk failure. Dedicated Cloud also provides snapshot backups which captures all the users' data to create an instant backup. The customer can then restore all the virtual machines to the same state as they were at a particular moment in time.

Totally isolated resources

All the user resources are interconnected using a private VLAN, thus completely isolating it from the outside and the other Dedicated Cloud customers. To connect to vCenter, the operations management suite for all virtualized resources, a user goes through an SSL tunnel. This protocol relies on encryption to guarantee the security of all the data transferred. The direct access to the virtual machines uses a virtual private network (VPN). The combination of a VPN and an authentication token ensures that all exchanges are totally secured between the user and the virtual machines. To protect even further vCenter and the virtual machines, users can limit accessing to it from specific IP addresses. Finally, Dedicated Cloud integrates vShield Zones, an application firewall for each virtual data centers, which protects the entire infrastructure.

Cloud Security: 3 questions to ask before selecting your service provider

by **Alexandre Morel**,
Product Manager Cloud Computing at OVH.com

According to analyst firm Markess International, the Cloud will grow more than 20% until 2014. Indeed, from emerging startups to large corporations, across all industries, IT professionals are choosing to move to the Cloud. But when faced with data migration and the variety of offers from Cloud Computing service providers, organizations have a hard time choosing, especially when security is a main concern. Here are a few questions that IT professionals must ask themselves before moving to the Cloud to ensure that their data are kept in a safe place.

1. Does the service provider own its data centers and network? Is it managing and maintaining them itself?
2. What are the best practices the service provider has put in place to guarantee the maximum security of your data?
3. Are you able to retrieve all of your data, at anytime and using a format compatible with your own tools?

**Study conducted between July and November 2012 among 370 French small businesses. http://www.markess.fr*

Did you know?

OVH.com Dedicated Cloud was awarded twice

VMware, the world leader in virtualization, which organized its Partner Exchange in Las Vegas last February, awarded OVH.com the Service Provider Partner Program 2013 trophy for the EMEA zone. OVH.com also received the Global Service Provider award for its global Dedicated Cloud solution.

For more information :
www.ovh.com/us

Upfront

Rise of the Bitcoin Millionaires

Early investors in the cryptocurrency are becoming its most powerful gatekeepers.

By Tom Simonite

Every time you spend bitcoins to buy a drink at Evr, a swanky bar in Manhattan, you make its co-owner, Charlie Shrem, just a little bit richer.

That's not only because a chamomile sour costs $17 (or 0.16 bitcoins). It's because whenever someone new uses bitcoins, the electronic currency's value tends to increase. Beginning in 2011, Shrem bought thousands of bitcoins for about $20 each. They have since been worth as much as $266.

Now Shrem, 23, is a millionaire—and one of a handful of bitcoin investors who are sinking their windfalls back into the bitcoin economy, starting companies and investing in others. "Infrastructure is what we need," says Shrem. "We've got to build, build, build: financial software, exchanges, and different payment products." In addition to his investment in the bar, Shrem founded Bitinstant, which makes it possible to buy bitcoins at Kmart and 7-Eleven.

Bitcoin originated in 2009, when its source code was posted online by persons unknown. Despite its mysterious beginnings, the way it works is transparent: the currency is produced when people carry out difficult cryptographic operations on computers, and then it's exchanged over an open-source peer-to-peer network. Bitcoins are immune to counterfeiting and don't rely on any central authority.

Initially, the bitcoin was mostly a curiosity. Among the first businesses to accept it were gambling sites, narcotics delivery services, and a farm selling alpaca socks. Yet Shrem and others have been thinking strategically, creating companies that comply with the law. They intend to make bitcoins a widely used form of money.

One reason to do so is that the number of bitcoins is limited: there's a theoretical maximum of 21 million, of which 11.4 million have been "mined" so far. That means the more people buy and use bitcoins, the more they tend to be worth. Anthony Gallippi, CEO of Bitpay, a company that helps online stores accept payment in bitcoins, says early buyers reinvesting in the technology are trying, among other things, to "ensure future returns" on the currency.

Bitcoin-related startups are attracting interest from mainstream venture capitalists as well. That's an important endorsement for the currency, but it gives pause to Roger Ver, 34, an electronics entrepreneur who has invested more than $1 million of bitcoin gains in more than a dozen startups. Like many enthusiasts, Ver was drawn to the bitcoin because of his libertarian views. He believes such decentralized currencies, if they replaced national ones, could make it impossible for governments to "finance their wars" by printing money. Mainstream investors, Ver says, may be unaware of the implications. "I don't think they fully understand how revolutionary Bitcoin will be," he says.

Roger Ver put his life savings into bitcoins. Now he invests in startups.

JESSICA LOUISE BERNARD, RECON INSTRUMENTS

BITCOIN VALUE

฿1 = $107

As of August 1

TO MARKET

Augmented Fitness

Recon Jet

COMPANY:
Recon Instruments

PRICE:
$599

AVAILABILITY:
Early 2014

It's like Google Glass, but for athletes: a pair of sunglasses with a display that can show vital statistics in the field of vision. The Recon Jet has a one-gigahertz processor and sensors to measure speed, position, elevation, and heart rate. It can also connect to third-party fitness trackers like those that map biking or running routes. In addition to offering applications that might appeal to cyclists and triathletes, the glasses can be paired with a smartphone to display messages and Web pages. Or wearers might use the high-definition camera to post images of their exploits on social networks even before their races are done.

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Upfront

50 Maximum employment expected at the New York City "factory of the future" run by Shapeways, a company that uses 3-D printing to make custom products.

3 QUESTIONS

Justin Rattner

The head of Intel's labs wants his company to move faster, even at smaller scales.

Intel has a new approach to get technology to market, called the "lab venture." Some technologies, like silicon photonics, will be commercialized while they're still in the labs. Why?
The problem, and it's not unique to Intel, is businesses are busy with their current products and customers. And someone [from labs] comes along and says, "If you just put another $50 million into this, we'll have this great product"—that rarely happens.

What changes to conventional electronic chips will be needed to keep pace with Moore's Law?
We're in a period of fairly rapid innovation. The industry built the same transistor for 40 years, and it just got smaller. [Then] at 65 nanometers transistors were leaking a lot, consuming a lot of power when they weren't even turned on. So at 45 nanometers we went to high-k metal gates [which work better at small scales] and literally changed everything: the architecture, the materials, the manufacturing process. Two generations after that and we're at 3-D transistors.

Is it getting harder to keep Moore's Law going?
Things are very small, and the physics is no doubt challenging. We can see ahead two, maybe three, generations and we feel pretty good about that, but beyond that it starts to get a little fuzzy. —*Tom Simonite*

COURTESY OF INTEL; BENDIK KALTENBORN

The Avatar Will See You Now

Medical centers are testing friendly ways to reduce the need for office visits by reaching into patients' homes.

By Jessica Leber

Most patients who enter the gym of the San Mateo Medical Center in California are there to work with physical therapists. But a few who had knee replacements are being coached by a digital avatar instead. The avatar, called Molly, interviews them in Spanish or English about the levels of pain they feel as a video guides them through exercises, while the 3-D cameras of a Kinect device measure their movements. Because it's a pilot project, Paul Carlisle, the director of rehabilitation services, looks on. But the ultimate goal is for the routine to be done from a patient's home.

"It would change our whole model," says Carlisle, whose hospital is looking for creative ways to reduce the pressures on its overextended budget and staff. "We don't want to replace therapists. But in some ways, it does replace the need to have them there all the time."

Receiving remote medical care is becoming more common as technologies improve and health records get digitized. Sense.ly, the California startup running the trial, is one of more than 500 companies using health-care tools from Nuance Communications, a company that sells

speech-recognition and virtual-assistant software.

Using Sense.ly's platform, patients can communicate their condition to an emotionally reactive avatar through their phone, desktop, or TV. The avatar asks the patient simple questions, and if programmed by a doctor, it can answer questions too—such as what a diabetes patient with high blood-sugar readings should eat that day. The software also collects data from other medical devices that a patient uses, such as a glucose meter. The reports sent to the doctor include red-flag notifications that should be acted on right away; charts, graphs, and analytics tracing the patient's progress over time; and a transcript of the voice interaction.

"We don't want to replace therapists. But ... it does replace the need to have them there all the time."

"A physician's time is always limited," says Benjamin Kanter, chief medical information officer at Palomar Health in San Diego. "For a long time, we've had the challenge of just getting information into the system. Now the system is starting to actually help me."

One big advance is the avatar itself: Molly can modulate her tone of voice and facial expressions, which are important in helping both patients and doctors to trust the interactions. Sense.ly cofounder Ivana Schnur, a clinical psychologist, says that sometimes patients are more willing to share sensitive information with a nonjudgmental avatar than with a doctor. Eventually, Schnur hopes, the system will be able to interpret and respond to a patient's facial expressions, which means it could be used in even more complex roles.

Global Warming Demands a Smarter Pollution Crackdown

Cleaning up power plants could be counterproductive unless diesel soot is reduced too.

By Kevin Bullis

Cutting our use of fossil fuels has proved a daunting challenge, but it might be possible to get relief from the effects of climate change by more aggressively reducing pollution from certain particulates—the ones that actually serve to warm rather than cool the planet.

A new study from the Scripps Institution of Oceanography concludes that if every country were to do what California has done in the last couple of decades to reduce the black carbon soot from diesel emissions, it would slow global warming by 15 percent. Reducing similar pollution from sources such as ships and cookstoves—which weren't included in the study—could help even more.

Aerosol pollutants such as sulfur dioxide, soot, and ozone are all bad for human health, but they have different effects on the climate. For example, sulfates that form from coal-plant exhaust reflect sunlight back into space, acting to shade the planet and cool it off. Black-carbon particles from diesel exhaust, on the other hand, absorb sunlight and heat up, warming the atmosphere. "When you add them together, we think that on balance they're cooling the planet," says Phil Rasch, a fellow at the Pacific Northwest National Laboratory. "If we could get rid of the ones that are warming the planet, then that would buy us some more time."

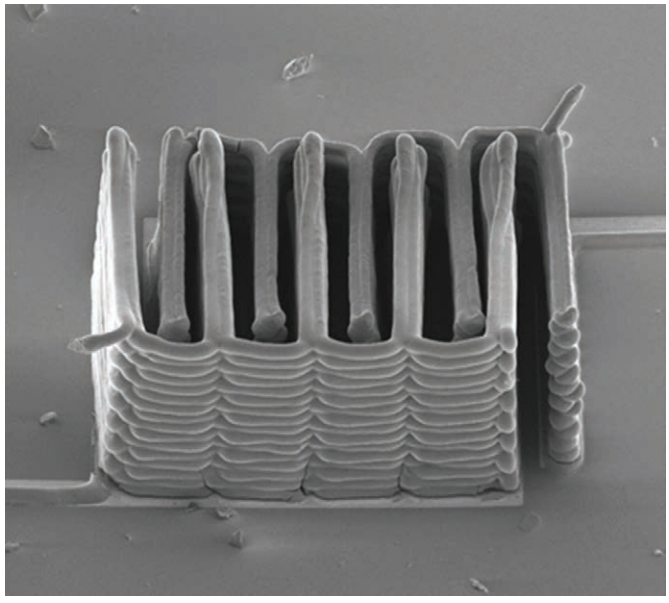
One advantage of going after black carbon is that these pollutants fall out of the atmosphere in a few days or weeks, so once emissions stop, the air quickly clears. Carbon dioxide stays in the atmosphere for hundreds of years.

Of course, it's ultimately important to reduce all pollution, since it kills millions of people a year. Selectively reducing pollutants "is an important strategy we can think about," says Lai-yung Ruby Leung, another fellow at the national lab, "but it needs to be carefully done."

Reducing soot from vehicles could pay off more than other pollution-reduction tactics when it comes to addressing global warming.

IMAGINECHINA / AP IMAGES

Upfront



This scanning electron microscope image shows a 3-D-printed lithium-ion battery. Tiny nozzles deposit anode and cathode inks in the precise architecture. The printed product shown here is roughly half a millimeter tall.

A Hint of 3-D Printing's Promise

Lab advances suggest how additive manufacturing could change the way electronic devices are made.

By Mike Orcutt

Today's 3-D printers can generally make things out of only one type of material—usually a plastic or, in certain expensive machines, a metal. They can't build electronics, optical devices, or objects with any kind of functions that require the integration of multiple materials. But recent advances suggest that this might soon change.

Harvard researchers recently unveiled what they say is the world's first 3-D-printed battery, made from two different electrode "inks." Led by Jennifer Lewis, a professor of biologically inspired engineering, the group used tiny nozzles to precisely deposit the anode and cathode inks, which contain nanoparticles of lithium titanium oxide and lithium iron phosphate, respectively. The researchers say these millimeter-scale rechargeable batteries could be printed in minutes and used to power things like small wireless sensors and medical devices.

Lewis's group has developed the materials and custom printer technology needed to print functional components besides batteries, such as electrodes and antennas made from inks containing metallic nanoparticles. The specialized equipment includes a nozzle that can print features as small as one micrometer.

The next step is to try to make "integrated electronics," says Lewis. It may take many years before something as complicated as a smartphone will be printable, but certain printed electronic products might not be too far off. Take hearing aids. Companies already print the plastic shell that sits in the ear cavity. The electronic components are assembled separately, and the devices use small batteries that must be replaced roughly every seven days.

"Imagine if you could 3-D-print the entire hearing aid," says Lewis.

The new opportunities are not limited to consumer electronics. For another advance in 3-D printing, see Demo, page 104.

TO MARKET

Power Ball

Soccket

COMPANY:
Uncharted Play

PRICE:
$99 or less

AVAILABILITY:
Fall

This soccer ball is for more than just fun and games: the Soccket stores the energy generated as the ball is kicked around. A removable tab on the surface of the ball covers an electrical outlet, where an LED lamp or cell-phone charger can be plugged in. A half-hour of play should translate into three hours of light; when fully charged, the ball should provide power for 72 hours. The Soccket was designed by Harvard students Jessica Matthews and Julia Silverman, who originally were thinking of poor countries where soccer is popular and electricity is unreliable or unavailable. But the ball and its six-watt output also could be useful at the beach, on camping trips, or during blackouts.

LEWIS RESEARCH GROUP; UNCHARTED PLAY

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PROGRAM HIGHLIGHTS

This year we examine the implications of alternative energy sources on society and the environment, plus big data, advanced manufacturing, smarter cities, digital currency, the latest developments in neuroscience, and more.

- **Jonathan Bush, CEO, Athenahealth**
  Delivering more efficient, personalized health-care services
- **Katharine Frase, VP and CTO, IBM Public Sector**
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35 Innovators Under 35 2013

For our 13th annual celebration of people who are driving the next generation of technological breakthroughs, we're presenting the stories in a new way. We've grouped them by categories that reflect the variety of approaches that people can take to big problems. First we introduce you to Inventors, who are creating new technologies. Next come Entrepreneurs, who are turning technologies into viable businesses. Then meet the Visionaries, who are anticipating how technologies can make life better, while Humanitarians are concentrating on expanding opportunities. Finally, the Pioneers are exploring new frontiers, setting the stage for future innovations.

This project takes months of effort. It begins with nominations from the public and *MIT Technology Review* editors. People who have been selected by our publishing partners as local Innovators Under 35 in several regions worldwide are also considered. The editors go through the hundreds of candidates and select fewer than 100 finalists, all of whom will be younger than 35 on October 1. A panel of judges rates the finalists on the originality and impact of their work. Finally, the editors take the judges' scores into account to select the group.

Next Year
Suggest candidates for the 2014 list at technologyreview.com/nominate

Judges

KRISTI ANSETH
Professor of Chemical and Biological Engineering, University of Colorado

DAVID BERRY
Partner, Flagship Ventures

EDWARD BOYDEN
Professor of Biological Engineering and Brain and Cognitive Sciences, MIT

YET-MING CHIANG
Professor of Materials Science and Engineering, MIT

JAMES COLLINS
Professor of Biomedical Engineering, Boston University

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JAVIER GARCÍA-MARTÍNEZ
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ERIC HORVITZ
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NAVAL RAVIKANT
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UMAR SAIF
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SOPHIE VANDEBROEK
Chief Technology Officer, Xerox

BEN ZHAO
Professor of Computer Science, UC Santa Barbara

DAPHNE ZOHAR
Founder and Managing Partner, PureTech Ventures

KEN ZOLOT
Senior Lecturer, MIT School of Engineering

Illustration by James Graham


a b c

Inventors 35

Q: Where do you get your creativity?

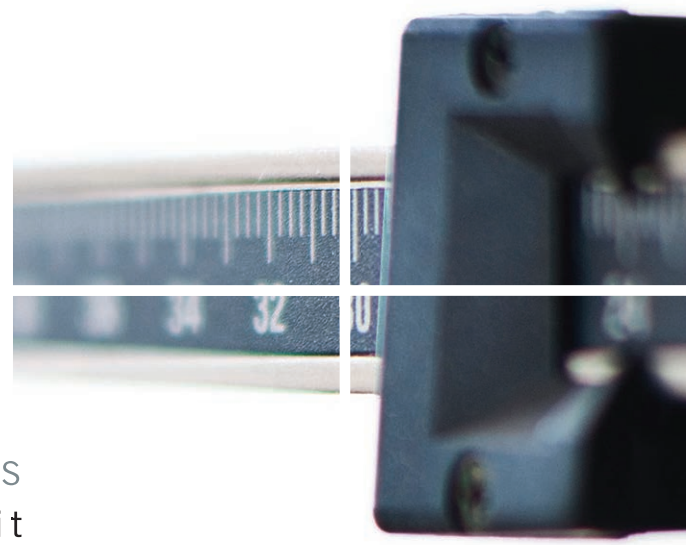
I wish I could summon creativity, but it doesn't come when I call.
I wait ... and wait ... and wait ... it slows me down, I nearly stall.
Then, out of nowhere, creativity appears ... in smiles and tears,
at night when I pray, when I watch my children at play,
when mowing the lawn, taking a shower, or even building a Lego tower ...
unfortunately, I cannot predict the hour.
But when creativity does finally arrive, full of thankfulness I let out a sigh.
There is no further need to fear, for I know that a solution to the problem is near.

John Santini was an Innovator Under 35 in 2002.

COURTESY OF ODTx MANAGEMENT

Illustration by James Graham

Cleveland Clinic



Finding Balance through Innovation

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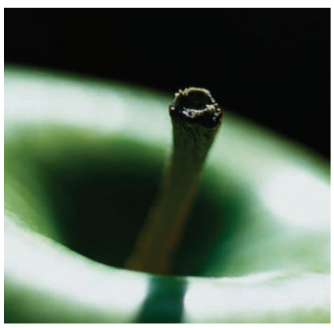
2013 Medical Innovation Summit

October 14-16, 2013



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Open-source software is making it nearly as easy to program a robot as it is to write an app.

MORGAN QUIGLEY, 32

Three decades ago, the availability of many versions of DOS helped spark the boom in personal computers. Today, Robot Operating System, or ROS, is poised to do the same for robots. Morgan Quigley programmed the first iteration of what grew into ROS as a graduate student in 2006, and today his open-source code is redefining the practical limits of robotics. Since version 1.0 was released in 2010, ROS has become the de facto standard in robotics software.

To visit Quigley's office at the Open Source Robotics Foundation in Mountain View, California, the organization he cofounded last summer to steward ROS, is to step into a future of robotics where hardware is cheap, and it's quick and easy to snap together preëxisting pieces to create new machines. Quigley's workspace is littered with dozens of mechanical fingers—modules that form a robotic hand. "The hands themselves can talk ROS," Quigley says. His T-shirt is emblazoned with a programming joke: *shirtcount++;*.

159,000
Number of industrial robots sold in 2012

Unlike more conventional robotic technology, Quigley's four-fingered hand is not controlled by a central processor. Its fingers and palm distribute computing chores among 14 low-cost, low-power processors dedicated to controlling each joint directly. That greatly simplifies the internal communication and coördination required to execute a task such as picking up a pencil. Both the software and electronics are open source. Any robot builder can take Quigley's design and use or improve upon it.

Ultimately, Quigley hopes, these innovations will lead to more agile, more capable robots that can perform a variety of jobs and don't cost tens or hundreds of thousands of dollars. And no longer will

Photographs by Timothy Archibald

Morgan Quigley is working on a robotic hand that is controlled using ROS.

1.

2.

1. The robotic fingers Quigley is working on have their own processors that separately control each of the joints.

2. The Turtlebot, shown here in Quigley's workspace, is an open-source robot that uses ROS.

3., 4. ROS makes various projects possible, as is evident from Quigley's cluttered desk; among the machines relying on ROS is Rethink Robotics' Baxter.

5. Some of the circuit boards used in the robotic hand.

engineers have to start from scratch to design the functions that go into a robot—they'll have an open-source base of code and hardware. Already, engineers using ROS are working on robots that do everything from folding laundry to repetitive operations in advanced manufacturing. "It will allow applications we couldn't dream of before," Quigley says.

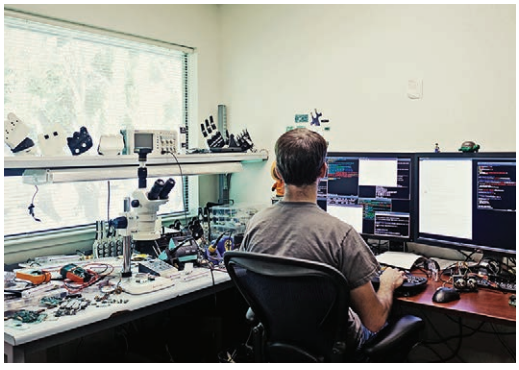
Masterstroke

Unlike many children of the 1980s and 1990s, Quigley wasn't enthralled by *Star Wars*' C-3PO or *Star Trek: The Next Generation*. Rather, he was mesmerized by the far more mundane but real Apple II computer at his elementary school. In class, he typed commands in the Logo language to move an animated turtle around the screen—the ancestor of ROS's turtle mascot. But it wasn't until 1998, when he entered Brigham Young University in Provo, Utah, that he encountered robots. He was hooked. "Robots are the meeting place between electronics, software, and the real world," he says. "They're the way software experiences the world."

When he arrived at Stanford for graduate study in machine learning, Quigley joined Andrew Ng's lab, where the students were collaborating on the Stanford Artificial Intelligence Robot, or STAIR. Typical industrial robots execute a single tightly defined task in a controlled environment, like an advanced automobile factory. Ng, however, envisioned a general-purpose robot that could execute diverse tasks in an uncontrolled environment. The signature STAIR challenge was getting the robot to respond productively to the request "Fetch me a stapler." To bring back the stapler, STAIR needed to understand the request, navigate hallways and elevators to an office, open the door, make its way to the desk, identify a stapler among other items of roughly the same size, pick it up, bring it back, and hand it off.

As Ng's teaching assistant, Quigley realized that the class needed a software framework that could integrate contributions from a few dozen students working asynchronously without bringing down the robot when one of their programs crashed. ROS was his solution: a distributed peer-

PREVIOUS SPREAD: DATA FROM THE INTERNATIONAL FEDERATION OF ROBOTICS



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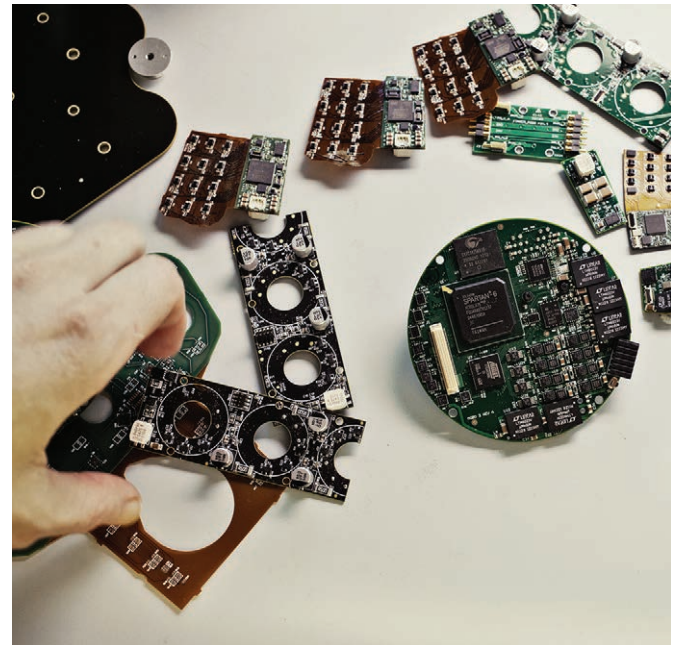


4.

5.

to-peer system designed to connect all the resources—technological and human—required to make a robot work.

In 2007, he began collaborating with Willow Garage, a Silicon Valley company that works on robots and open-source software. For the next two years, Quigley oversaw the ROS architecture while Willow Garage's programmers extended his initial work. Released in 2010, ROS quickly became the dominant software framework for robotics.

Despite its name, ROS isn't really an operating system. It's a framework that enhances conventional operating systems (theoretically, any OS; in practice, Linux). It provides software modules for performing common robotics functions such as motion planning, object recognition, and physical manipulation. So if you want a robot to map its surroundings, you don't have to write that code; you can simply plug in the ROS software module. As an open-source product that can be freely modified, it attracts a community of users who are constantly improving and extending its capabilities.

Any number of independent modules can run at a given time. Modules can be connected for testing, disconnected for debugging, and reinstated without destabilizing the network as a whole. In this way, ROS allows a robot to be controlled by any number of computers running any number of programs—a laptop focusing on navigation, a server performing image recognition, an Android phone issuing high-level instructions. It all happens in real time as the robot wanders about.

The masterstroke in Quigley's design is not strictly technical but social. Members of the community who produce a finished release can distribute it themselves, rather than having to house it on central servers. "That's a big deal in terms of giving people the credit they deserve and allowing them to control their contributions," Quigley says. "Their code isn't lost in this beast called ROS."

Grand Plan

Quigley's ambition is to make ROS a productive starting point for any kind of robotic system—large or small, expensive or cheap, academic or commercial, networked or stand-alone.

Adapting ROS for low-cost processors is critical if the software is to play a key role in next-generation designs. Cheap processors are becoming more capable, opening an opportunity to bring the intelligence that has been concentrated in desktop-class processors to the CPUs that manage robotic wheels, joints, and cameras. Where image recognition was once a function of a rack of servers, soon it might be managed within the camera.

Quigley also wants ROS, which was designed to control one robot at a time, to move into environments that use multiple robots. Settings such as warehouses or factory floors would benefit from squadrons of them operating in a coördinated way. Beyond that, it's not hard to imagine robot fleets managed in the cloud: users could send ROS commands to a data center and from there to an automaton. "ROS might tie into an online knowledge base," Quigley says, "so if someone says, 'Get the stapler off my desk,' it might retrieve a CAD model of a stapler from the cloud." —*Ted Greenwald*

Images of the beating heart could make it easier to detect and treat heart disease.

CHRISTINE FLEMING, 30

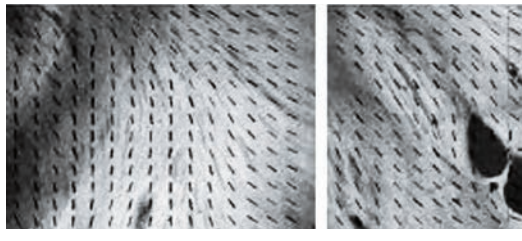
Abnormal orientation of cells in the heart wall is a clue to arrhythmias, which can be fatal. The images at right, created using optical coherence tomography, show the orientation of a rabbit's heart-muscle cells. Christine Fleming's approach to diagnosing arrhythmias could be an alternative to invasive biopsies.

Christine Fleming is trying to give cardiologists a powerful new tool: high-resolution movies of the living, beating heart, available in real time during cardiac procedures. Such technology might also one day help physicians pinpoint the source of dangerous irregular heart rhythms without invasive biopsies. It could even help monitor treatment.

Her invention uses optical coherence tomography (OCT), a technique that captures three-dimensional images of biological tissue. A specialized catheter with a laser and small lens near its tip is threaded through the arteries. When the laser light reflects off the heart tissue, it is picked up and analyzed to create an image. OCT has a higher resolution than ultrasound and captures images faster than magnetic resonance imaging, or MRI. But today OCT has limited cardiac application—usually to search the arteries for plaques. Fleming, an electrical engineer who joined the faculty at Columbia University this year, has designed a new type of catheter capable of imaging heart muscle.

One of the primary uses of the technology will be to locate, and monitor treatment for, irregular heart rhythms that are typically caused by disruption of the heart's regular tissue structure. In patients with arrhythmias, which can lead to heart failure, surgeons often burn away the affected tissue with targeted radio-frequency energy. Currently they perform the procedure somewhat blind, using their sense of touch to determine when they have come in contact with the muscle wall. "Since the physician doesn't have a view of the heart wall, sometimes the energy is not actually being delivered to the muscle," says Fleming, who adds that the procedure can last for hours. Fleming has shown in animal tests that her catheter, which uses a novel forward-facing lens, can successfully monitor the ablation in real time. Algorithms that help distinguish untreated from treated tissue offer further guidance.

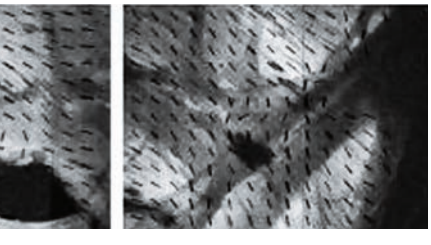
325,000
Number of sudden cardiac deaths each year in the U.S.



Photograph by Beth Perkins

Fleming is also developing algorithms to help improve the detection of arrhythmias by precisely measuring the three-dimensional organization of heart muscle. The technique works best when the tissue has been chemically treated to make it clearer, and thus easier to image. But her team at Columbia is now improving the algorithms so that the method works without this treatment. She hopes that in time the technology could supply an alternative to invasive biopsies, which are sometimes used to diagnose unexplained arrhythmias or to monitor heart health after transplants.

Fleming's arrival at Columbia earlier this year was something of a homecoming. As a high-school student in New York City, she interned at the NASA Goddard Institute for Space Studies, which is down the street from her current lab. But in the intervening years her engineering interests have increasingly become tied to medicine; her inspiration for studying the electrical properties of the heart came when she studied electrical engineering and computer science as an undergraduate at MIT. Working with physicians is especially exciting, she says, because "you get the sense that one day your technology will be used." *—Emily Singer*



A revolutionary type of 3-D display could provide a new look to moving images.

DAVID FATTAL, 34

David Fattal, a French-born quantum physicist who is now a researcher at HP Labs, is a master of nanoscale light tricks, and the feat he unveiled this year is his most impressive yet. It's a new kind of display that can project colorful moving images, viewable in three dimensions from multiple angles without any special glasses.

Fattal's invention, which he calls a "multidirectional backlight," consists of a thin piece of glass (or plastic) with light-emitting diodes mounted on its edge. Thanks to its particular design, which governs the angle at which the light is propagated, the device takes advantage of total internal reflection—the same optical phenomenon used in fiber optics.

Light from the LEDs doesn't escape from the material until it hits nanoscale features etched or imprinted on the surface—what Fattal calls "directional pixels." Composed of grooves smaller than the wavelength of the light, the pixels allow for precise control over the direction in which individual rays are scattered, shooting the different colors of light in specific directions. The result is colorful images that "seem to come from nowhere," says Fattal.

In a paper published in *Nature* in March, Fattal and colleagues presented prototypes capable of projecting static and moving images viewable from 200 angles. They performed the trick by overlaying their novel backlight with an ink-printed mask that blocked certain colors and allowed others through. One of the first images they produced was that of a turtle hovering immediately above the glass. Fattal has also used a modified liquid crystal display to produce simple moving images.

Since the setup creates realistic, hologram-like 3-D images without the need for bulky optical equipment, it could be attractive for use in smartphones, tablets, smart watches, and other mobile devices.

Projecting high-quality images, however, will require much larger and more complicated pixel arrays and advanced mechanisms for handling a huge number of data-rich images quickly. And creating 3-D content that can be enjoyed from all the many vantage points accommodated by this technology will be no small task either. But in his ingenious use of nanotechnology, Fattal has given us the possibility of seeing images and videos in a whole new light.

—Mike Orcutt

Illustration by Golden Cosmos

Determining the origin of a phone call cuts fraud, including identity theft.

VIJAY BALASUBRAMANIYAN, 33

PROBLEM: Fraud over the telephone costs banks and retailers more than $1.8 billion a year. Criminals who call customer service lines pretend to be legitimate customers and often dupe the operators into approving a transfer or divulging sensitive account information.

SOLUTION: Vijay Balasubramaniyan can detect where a call is coming from by analyzing its audio quality and the noise on the line. If a call purportedly from one place has the audio signature of a call from the other side of the world, his technology can sound an alert. The company he founded, Pindrop Security, counts several banks and an online brokerage firm as customers.

The audio quality of a phone call is affected in subtle ways by many factors, including the networks and cables it travels through. Pindrop makes hundreds of phone calls per hour to build a database of what, for example, a cell phone on a particular network in India sounds like. The service can then compare those files with the audio patterns in calls to customer service centers to determine whether a call is coming from where it says it is.

—Conor Myhrvold

The cofounder of Nest, which invented a thermostat that learns people's preferences, explains what's next.

MATT ROGERS, 30

You and Tony Fadell, one of the creators of the iPhone and iPod, started Nest after both of you left Apple. Wasn't being in charge of iPod and iPhone software development your dream job?
I had a Mac Plus when I was three years old, and I loved Apple as a company. I flew out to California [from Gainesville, Florida] with my grandparents on my 13th birthday to go out to Cupertino. And I told my grandparents then, "Yeah, I'm going to work at Apple, for sure."

Then why leave at just 26 years old?
Basically, I pushed as hard as I could, worked incredibly hard, built tons of stuff, built teams, built products, and loved it. But somewhere around my four-and-a-half-year anniversary at Apple, we were working on another generation of iPods and another generation of iPhones and starting work on the third generation of iPads, and I was ready for something new.

Going from smartphones to smart thermostats isn't an obvious jump.
Tony and I had lunch back in October of 2009. I told Tony, "I'm thinking about leaving Apple; I'm thinking about starting my own company, and I'm looking at smart-home stuff." And he stops me right there. He goes, "You know what? A smart home is for geeks. No one wants a smart home—it's a stupid idea. Focus on doing one thing and doing it really well."

Programmable thermostats existed before the Nest, but they were awful.
The programming was tough. They were like the early '80s VCRs, where you'd push a button 15 times to change it to Tuesday and change the temperature there. Part of it is that the product was designed to be sold to a contractor and not designed for a user.

In contrast, the Nest is a lot like the iPhone—it's easy to figure out how to use.
The product that we built is basically a smartphone on the wall.

And there's nothing I have to push 15 times. There aren't even any buttons—you just turn the entire metallic case. That's very Apple-like.
When we were building Nest, we were going to build it like any great product and design company. You'd have great industrial design, great hardware engineering, great software engineering, great services, great consumer marketing—all those things.

One way the Nest saves energy is by detecting when no one's home. But there's got to be much more you can do on the back end, to make plans based on weather forecasts and other data.
There's always more. Since we've launched the product, we've done something like 21 software updates, of which I'd say five or six have included major energy-saving algorithm improvements, and we're always finding more. The more detail we have, the more users we work with, the more homes we're in, the more we're learning. It's a very long tail of things we could be doing. You can see multiple products.

Which brings us back to your original ideas about a smart home. The Nest could become a hub for controlling many things, not just heating and cooling.
It could be, yes.

COURTESY OF NEST

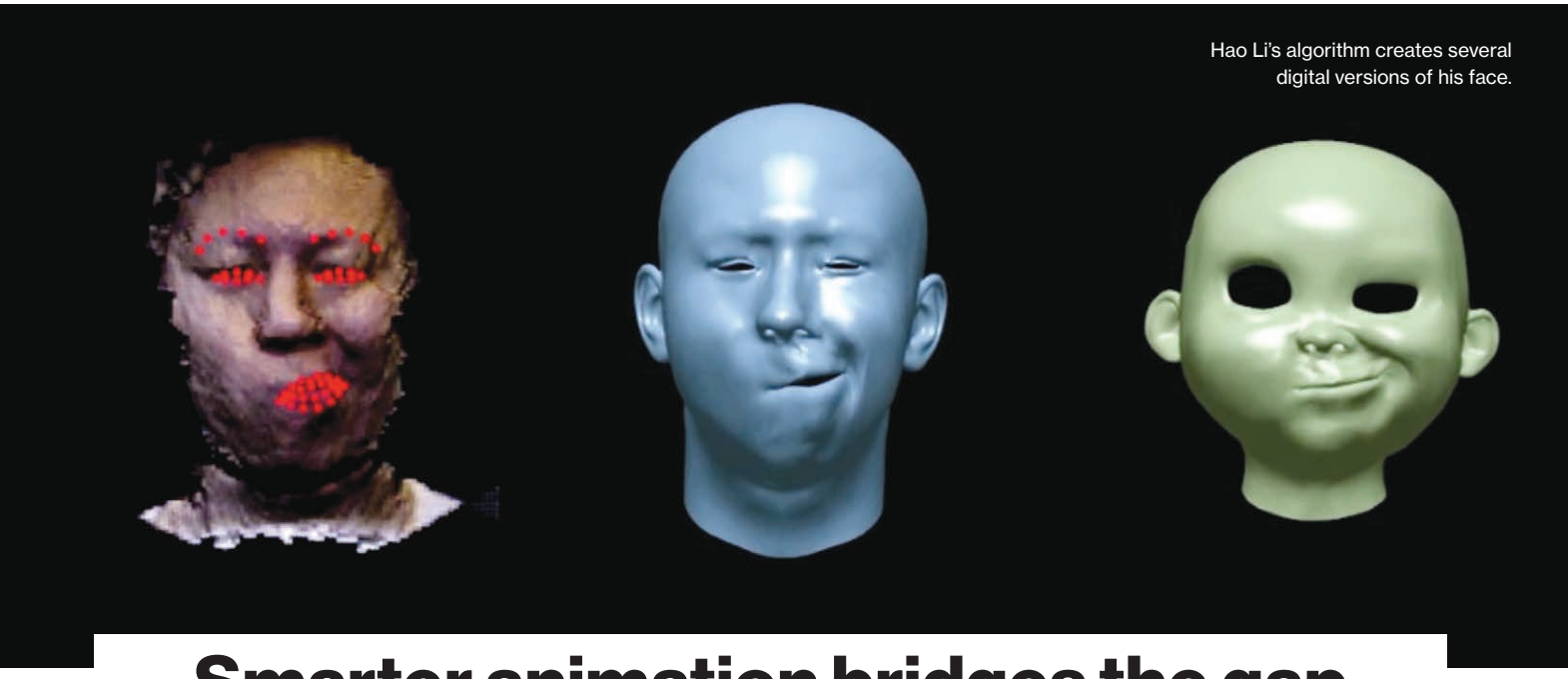
Portrait by Brett Affrunti

But yet you guys say only geeks want smart homes—
Wait, wait. I don't believe in networking connectivity just for the sake of having things connected. There's got to be a really good reason why you'd want to do it. You don't want to put networking in your microwave oven. What would it do?

So what does make sense? What might a home in the future do differently?
Today when you arrive home, the Nest sensor sees you and starts cooling your home so you're comfortable. And if you extrapolate to the future, you're driving home from work; your phone knows that you're driving home, or your car itself knows you're driving home, and lets Nest know, "Matt will be home in 15 minutes; we'll start preparing the home for his arrival." And then, as you get closer to the door, things might change—it might turn the song list on and play my favorite music, or turn the lights on—or, when I leave, do the opposite.

That sounds like a geek dream to me—less about reducing energy than increasing comfort.
These things go hand in hand, actually. Part of the promise of Nest is that we're going to keep your home comfortable, and may actually even make you more comfortable, while also helping you save. *—Brian Bergstein*

Nest's thermostat uses an interface that's simple and easy to understand.



Hao Li's algorithm creates several digital versions of his face.

Smarter animation bridges the gap between the physical and digital worlds.

HAO LI, 32

Hao Li remembers watching *Jurassic Park* as a kid: "That moment of seeing something that didn't exist in reality, but it looked so real—that was definitely the one that made me think about doing this," he says. Li tells me the story one afternoon while we dine at the cafeteria of Industrial Light & Magic, the famed San Francisco visual-effects studio where he has been working on a way to digitally capture actors' facial expressions for the upcoming *Star Wars* movies. When *Jurassic Park* came out, Li was 12 years old and living in what he calls the "boonie" town of Saarbucken, Germany, where his Taiwanese parents had moved while his father completed a PhD in chemistry. Now, 20 years later, if all goes to plan, Li's innovation will radically alter how effects-laden movies are made, blurring the line between human and digital actors.

Visual-effects artists typically capture human performances through small balls or tags that are placed on an actor's face and body to track movement. The data capturing the motion of those markers is then converted into a digital file that can be manipulated. But markers are distracting and uncomfortable for actors, and they're not very good at capturing subtle changes in facial expression. Li's breakthrough involved depth sensors, the same technology used in motion gaming systems like the Xbox Kinect. When a camera with depth sensors is aimed at an actor's face, Li's software analyzes the digital data in order to figure out how the facial shapes morph between one frame and the next. As the actor's lips curl into a smile, the algorithm keeps track of the expanding and contracting lines and shadows, essentially "identifying" the actor's lips. Then the software maps the actor's face onto a digital version. Li's work improves the authenticity of digital performances while speeding up production.

Li is amiably brash, unembarrassed about proclaiming his achievements, his ambitions, and the possibilities of his software. His algorithm is already in use in some medical radiation scanners, where it keeps track of the precise location of a tumor as a patient breathes. In another project, the software has been used to create a digital model of a beating heart. Ask him if his technology can be used to read human emotions or if he'll find some other far-off possibility, and he's likely to say, "I'm working on that, too."

When I ask if he speaks German, Li smiles and says he does—"French, German, Chinese, and English." This fall, he will begin working in Los Angeles as an assistant professor in a University of Southern California computer graphics lab. But Hollywood movies are not the end game. "Visual effects are a nice sandbox for proof of concepts, but it's not the ultimate goal," Li says. Rather, he sees his efforts in data capture and real-time simulation as just a step on the way to teaching computers to better recognize what's going on around them. *—Farhad Manjoo*

COURTESY OF HAO LI

How good can computers get at predicting events?

KIRA RADINSKY, 27

In 2012, when Cuba suffered its first outbreak of cholera in 130 years, the government and medical experts there were shocked. But software created by Kira Radinsky had predicted it months earlier. Radinsky's software had essentially read 150 years of news reports and huge amounts of data from sources such as Wikipedia, and spotted a pattern in poor countries: floods that occurred about a year after a drought in the same area often led to cholera outbreaks.

The predictions made by Radinsky's software are about as accurate as those made by humans. That digital prognostication ability would be extremely useful in automating many kinds of services.

Radinsky was born in Ukraine and immigrated to Israel with her parents as a preschooler. She developed the software with Eric Horvitz, co-director at Microsoft Research in Redmond, Washington, where she spent three months as an intern.

Radinsky then started SalesPredict, to advise salespeople on how to identify and handle promising leads. "My true passion," she says, "is arming humanity with scientific capabilities to automatically anticipate, and ultimately affect, future outcomes based on lessons from the past." *—Matthew Kalman*

After hitting the video-game jackpot, an independent game developer reflects on his success.

MARKUS PERSSON, 34

Markus Persson—better known as Notch to his millions of followers—is an unlikely technology megastar. A quiet, unassuming Swede, he looks like the typical video-game programmer, with thinning hair and a thickening torso; his defining features are twin dimples when he smiles and a jet-black fedora, an accessory he is rarely seen without. But Minecraft, an independent video game he created and released on the Internet in May 2009, has sold 30 million copies, making him rich and famous.

Persson is now a hero to a generation of young game players, who hang on his every tweet. Last year he earned more than $100 million from Minecraft and its associated merchandise. But the programmer appears largely unchanged by the money. While he routinely travels by private jet and is well-known for hosting lavish parties in Minecraft's name, his main material indulgence is ensuring he always has the latest computer.

Though Persson might be little changed by success, Minecraft has transformed video games. A rudimentary-looking Java game that doesn't require the latest computer to run, it places its player in the middle of a pastoral landscape that represents a unique and randomly generated world. Trees, sand, gravel, and rocks are each represented by a different type of block, and these can be harvested and subsequently "crafted" into different objects and tools. One mouse button is used to harvest the blocks, the other to place them. In this way players are able to shape the game's world to suit their whims. The blocks can be rearranged to create structures and settlements as elaborate as the player's imagination permits.

Persson believes his success is a once-in-a-lifetime event, a freakish hit of the sort that strikes some creative people with unrepeatable fortune. Minecraft's popularity has brought unfamiliar attention to the designer, whose every idea is now pored over by a watching world. Regardless of the scrutiny and accompanying creative jitters, Persson continues to be a prolific and ambitious game inventor. His next project is a resource-trading game set in space. *—Simon Parkin*

$21 billion
Global sales of online video games in 2012

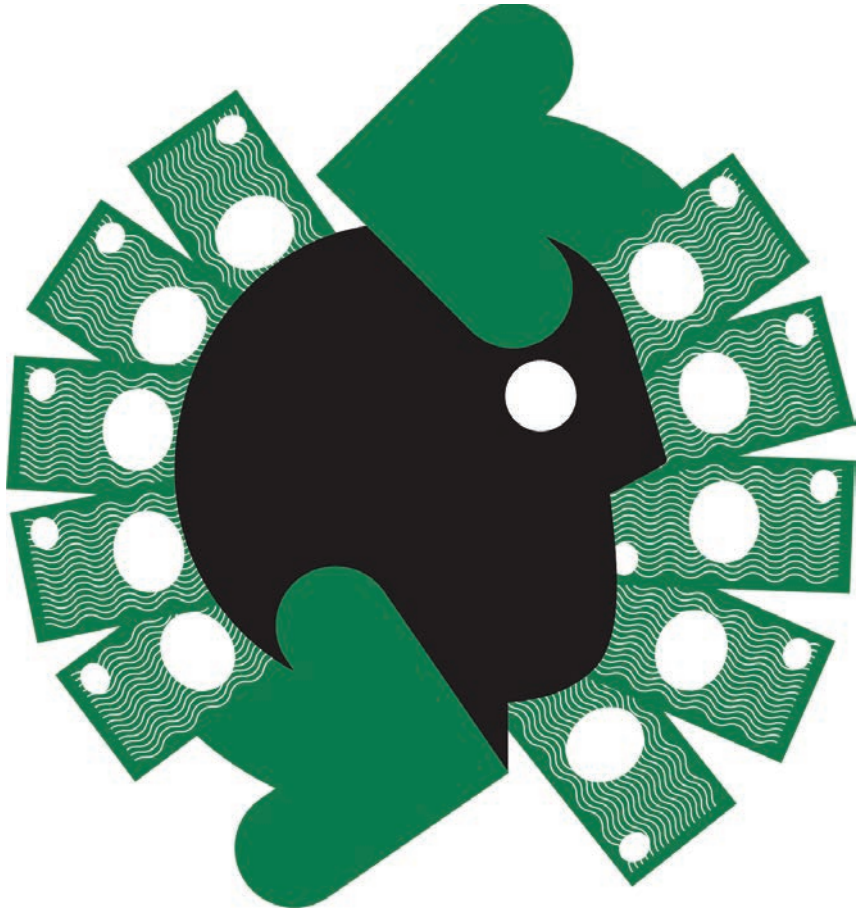
COURTESY OF DIVICI/PLANETMINECRAFT.COM; DATA FROM DFC INTELLIGENCE

Portrait by Brett Affrunti

Entrepreneurs 35

Q: What makes an entrepreneur great?

A: I don't think entrepreneurship can be taught. I don't think it's like, "Do these five things and you'll be an entrepreneur." And by extension, I don't think it's "Do these five things better and you'll be a better entrepreneur." Everyone I know has their own style. The unifying characteristics are all the same: drive, inability to play well with others, decisiveness, general indifference to reason on occasion. Entrepreneurship is this weird process of constantly flying blind, by the seat of your pants, and also of constantly projecting this extreme confidence that everything is going to be just fine. And the only way you can do it is you have to believe that it really will be. So it's the continuous ability to suspend your own disbelief, basically. *—Max Levchin, a founder of several companies, including PayPal, who was an Innovator Under 35 in 2002.*



COURTESY OF HUBERT BURDA MEDIA/PICTURE ALLIANCE/JAN HAAS

Illustration by James Graham

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Digital payment systems dreamed up in the Web era still piggyback on credit card networks. There ought to be a faster and cheaper way.

BEN MILNE, 30

The Internet can move data from one person to another in a fraction of a second. Why can't it do the same for money? Ben Milne asked himself that question, and the answer led him to found Dwolla, a digital payment network that could make it faster, easier, and safer for money to change hands.

Dwolla is on track to process over $1 billion for 250,000 consumers and businesses in 2013. It has amassed $22.5 million in venture capital and emerged as a threat not only to the likes of PayPal but also to venerable institutions such as Visa. Yet Milne is not a financier or a university-educated wunderkind. He sports the shaved head and full beard of a San Francisco hipster, but he's an Iowan who is building his company in Des Moines.

Seated in a conference room at the Silicon Valley offices of his latest investor, Andreessen Horowitz, where the founders of Facebook, Twitter, and Skype got funding that led to Internet glory, Milne discusses the complex world of payments with confidence and liberal use of the phrase "the reality is."

$66.5 billion
Fees paid by U.S. merchants on card transactions in 2012

"The reality is, the way we exchange money makes money worth less," he says. If you sell something for $100 with a $10 margin, your profit would be $7.50 or less if the customer paid with a credit card. "You can't drive down the fees with regulation, because that's the technical cost," he says. "To remove it, you need a better mechanism for exchanging value. That's Dwolla."

Milne grew up in Cedar Falls, Iowa, where he passed the time playing soccer and repairing broken appliances his grandmother collected. When he was in middle school, his father, a dentist, was diagnosed with Parkinson's disease but was determined to do as much as possible while he still could: he built a public soccer

DATA FROM THE NILSON REPORT

Photographs by Ryan Donnell

stadium and golf course. Those actions held an important lesson for Milne. "I remember thinking, he didn't know anything about that, but he figured it out and did it," he says. "I realized that all you need to do, a lot of the time, is decide what you want to do and just get it done."

Milne started his first company, which made audio speakers, with $1,200 in savings in 2001, while he was a senior in high school. He dropped out of the University of Northern Iowa to build the business, and by 2008 he was racking up $1.5 million in sales annually. But he was troubled by costs. "We were spending $55,000 a year in credit card fees," he recalls. "I thought, that's insane. I'm making the sales, and I just sent these people's kids to college."

Milne became convinced that no solution existed and that the only way to get one was to build it himself. Over the next two years, he figured out how to do it. "He would commit himself to doing seemingly impossible things," recalls Matt Harris of Bain Capital Ventures, who funded Dwolla during this period as a managing partner at Village Ventures. "Then we'd meet three months later, and he would have done them and have a new set of impossible things."

Dwolla launched nationally in December 2010 and was moving $1 million a day in July 2011. By the end of last year it was doing nearly three times that volume. "It was not a beautiful, predictable, calculated process," Milne says. "It was 'Don't go broke and don't stop.'"

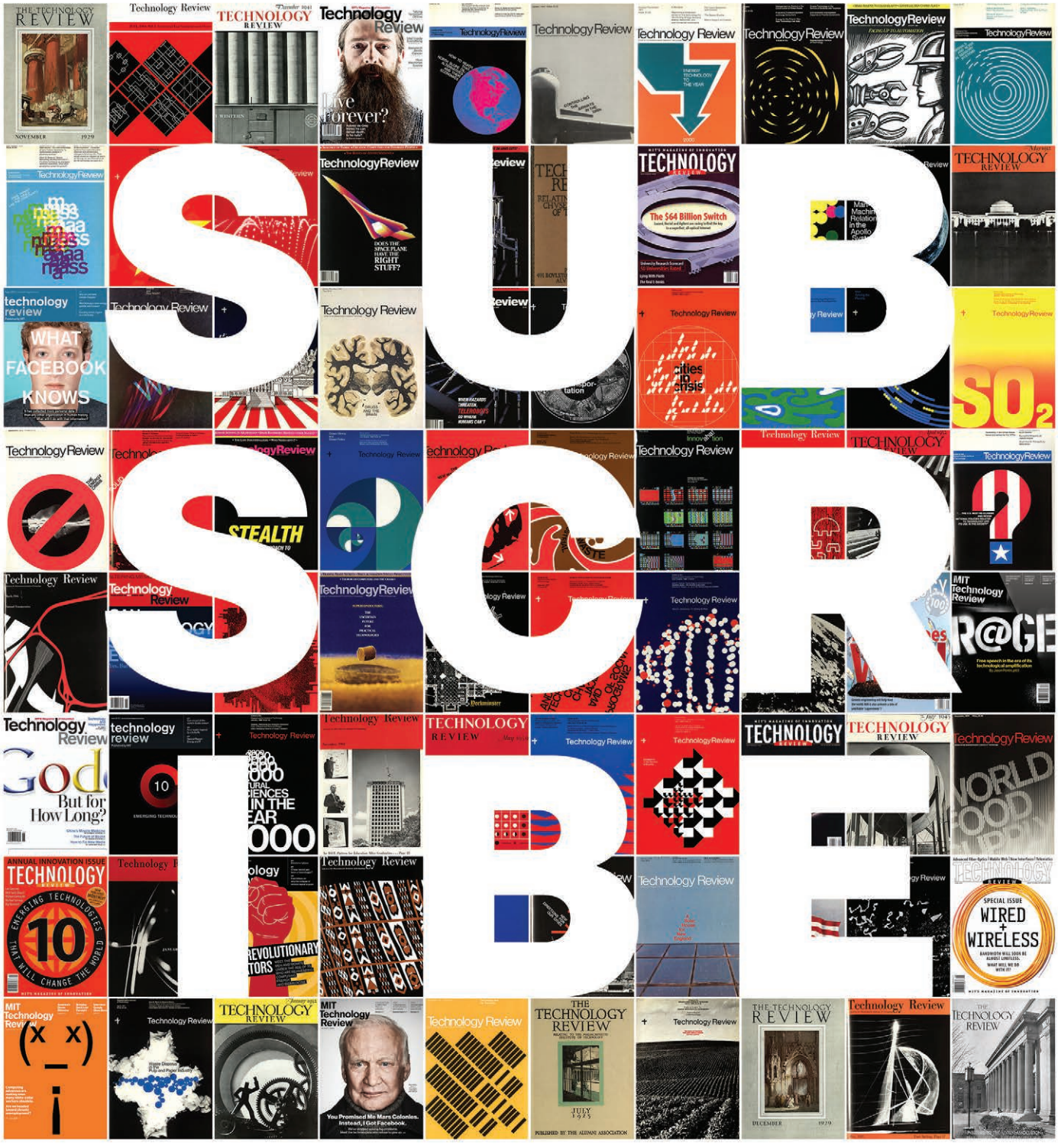
In a market overflowing with mobile payment services and digital cash schemes, Milne's service is unique. Nearly all electronic payment systems, including PayPal, are built on the four financial networks that carry noncash transactions. Dwolla (as in "dollar" plus "Web") can avoid all of them. It has built its own network, known as FiSync, that connects to banks directly. So Dwolla doesn't need to pay fees to anyone. It can be used in just about any scenario: at a cash register, from a phone or a desktop PC, person to person, business to business, bank to bank.

Merchants get the most obvious benefit: the recipient of a Dwolla transfer pays 25 cents per transaction over $10, but nothing for deals worth less than that. Compare that with the 2 to 3 percent plus 30 cents per transaction typical of credit cards and gateways to credit networks. For consumers, the system is simple: they can send money to an e-mail address, phone number, Twitter handle, or Facebook friend; the recipient will get a message prompting him or her to sign up with Dwolla to accept the money. And banks benefit because Dwolla can move money in real time, a capability no other network has. The Automated Clearing House, or ACH, the bank-to-bank transfer system that credit and debit cards depend on, theoretically settles in 24 hours. But in practice it can take up to five days, creating a risk that payers will turn out not to have the money they thought or claimed they had at the moment of a transaction.

FiSync also adds layers of security. Among other things, money is transferred by means of digital tokens that confer authorization to execute specific transactions; account details themselves are not transmitted. Consequently, Dwolla claims fraud rates an order of magnitude smaller than other transaction systems do.

Technically, FiSync is simple. Logistically, it requires that Dwolla ink deals with every bank in the country. That's because each bank maintains its own database of accounts. A given institution can transfer funds electronically within its own walls instantly and freely, but to go outside, it needs to use the ACH or wire networks. FiSync would replace those by connecting to every bank's database directly.

Milne has signed up only 16 financial institutions but says he is on the verge of dramatically expanding that number. It will take a lot of legwork, but he is ready to proceed bank by bank. "In Silicon Valley, people are looking for a silver bullet," he says. "I look at it like a Midwesterner: I have an ax and I'm going to cut down a tree. You close the first customer, then the second, then the third. It's hard work, but that's the way you do it." *—Ted Greenwald*



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In the jobless economic recovery, an online labor marketplace thrives.

LEAH BUSQUE, 33

When Leah Busque worked as a software engineer for IBM's Lotus group, her favorite part of the job was attending an annual conference at Disney World, because it was the only time developers in her division got to meet customers. It made her realize she wanted to start a business of her own.

So in 2008, just before the financial crisis hit, she quit IBM to work on an idea she had: that people should be able to go online and easily hire their neighbors to do quick errands and other odd jobs. She later called it TaskRabbit.

She assumed that the jobs would mainly attract college students who needed extra cash. But the interest turned out to be much wider. Today, 13,000 TaskRabbits bid for jobs in 14 U.S. cities. Three-quarters of them hold bachelor's degrees; 5 percent have PhDs. These "micro-entrepreneurs," as Busque calls them, include retirees, mothers, the unemployed, and the underpaid. They do everything from delivering lunches and fixing toilets to dressing up as a hot dog for a surprise birthday party (true story). Pay might be as low as $10 per task, but some skilled jobs fetch hundreds, especially for TaskRabbits with high reputation rankings on the site. The employer pays a 20 percent commission to TaskRabbit.

14%

The U.S. unemployment rate if you include part-timers and other "marginally attached" workers

Busque says TaskRabbit has just scratched the surface of what it can do. It recently expanded to help small businesses or event planners find temp workers without going through expensive placement agencies or the wilds of Craigslist.

"Our vision is huge: to revolutionize the way people work," she says. "It's about offering people more choice on how they work, what their schedules are like, how much they get paid, [and the choice of] being their own bosses." —*Jessica Leber*

DATA FROM U.S. BUREAU OF LABOR STATISTICS

Photograph by Timothy Archibald

When the Internet was getting big in Russia, he was in the right place at the right time. Now he hopes to do it again with personal robotics.

DMITRY GRISHIN, 34

Dmitry Grishin was born on a missile base in the Soviet Union. He grew up around technical people working on secret projects; his father designed radar systems for the MiG-29 jet fighter.

In Russia, every boy wanted to be a spaceman. But Grishin was taken by robotics. He remembers seeing his first Western VCR when he was about 12 and being fascinated by the mechanical movement that drew the tape into the player. There were Russian robots to admire as well, like Lunokhod 2, a remote-controlled lander that had set down on the moon in 1973. "That you can sit on Earth and drive the device—I thought it was so cool," he says.

Then came the end of the Soviet Union and the tarnishing of its glories. Grishin left home for Moscow State Technical University with a few rubles. But he had a knack for programming and for managing others. By the time he was 20, he was overseeing programmers in Florida for a computer-aided design company from his student hostel in Moscow.

Those were the early days of the Russian-language Internet, known as Runet. The goal was to copy U.S. ideas, much as eBay was copied by Molotok.ru, an auction site Grishin joined in 2000. To stretch Molotok's limited resources, Grishin hunted online for equipment being sold off by failed U.S. dot-coms, scooping up $100,000 networking devices for $5,000. Later, to expand Mail.ru, an e-mail service, he bought cheap servers from China and used software to create redundancies. "We played a lot of tricks to create a big technology," he says.

By 2001, Molotok and other struggling Web projects were swept together by Yuri Milner, the Russian financier who later made a killing on Facebook shares. Milner made Grishin CEO of the combined company, which is now called Mail.ru Group. Was it typical in Russia to be picked as CEO at just 24? "There's not that much typical stuff in Russia," Grishin deadpans.

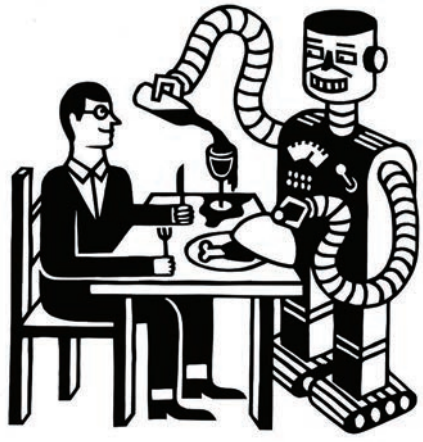
To be sure, Mail.ru is Russia's Yahoo, not its Google. It's the site with cat pictures and tacky come-ons. It owns chat services, e-mail, and a social network, Odnoklassniki ("classmates"), that attracts a lower-tech crowd. Even so, when Mail.ru staged the first large IPO by a Russian Internet firm, in 2010, it raised $912 million. Grishin has managed to steadily increase the profits from ads and online games. "If you watch the performance of the company, then you'd say he's an innovative visionary who built well on the business model," says investment banker Terry Schallich of Pacific Crest Securities, which helped manage Mail.ru's IPO.

Russia's non-Roman alphabet made foreign services slow to enter the country. But now that Russia has more Internet users than any other country in Europe, it's not clear how long the domestic Internet firms can maintain their separate fiefdom. Facebook has started to become very popular. Grishin's response has been to try to expand Mail.ru outside of Russia, or "to go on the attack," as he says. In 2012, Mail.ru launched a Twitter rival that it built in a month; it offered big pictures and video (which Twitter now offers too). It didn't succeed, but Grishin has invested heavily in massive multiplayer games that may yet find an international market.

What has most raised Grishin's profile outside Russia was his launch in 2012 of Grishin Robotics, a venture firm dedicated to what he calls "personal robotics," in which he invested $25 million, or about 15 percent of his net worth, he said in a 2012 interview. His fund has invested up to half a million dollars each in companies like DoubleRobotics, maker of a $2,500 telepresence robot, and RobotAppstore, a site to download games or instructions into toy robots.

There's something childlike about Grishin's interest in robotics. He likes to imagine automated chairs that would swoop to wherever someone wants to sit. Or drones that fly over a wedding to snap pictures. The holdup to these visions has been technology. Now, with inexpensive sensors and software, he thinks robots—like e-mail in Russia a decade ago—are ready for mass consumer markets.

—Antonio Regalado



COURTESY OF DMITRY GRISHIN

Illustration by Golden Cosmos

The mPedigree Network, based in Ghana, lets people determine with a text message whether their medicine is legitimate.

BRIGHT SIMONS, 31

I grew up in Ghana, where we'd inherited the British boarding school system. At Presbyterian Boys High School, many upperclassmen were abusive toward the younger students. Once, I was made to stay awake all night in a kneeling position outside. But in my final year at school I became student council president and led efforts to reduce abuses. That experience opened my eyes to a whole new world of fighting the system—of being an activist. And this led directly to my becoming a technology innovator.

A few years later, while at Durham University in the U.K., I transferred that instinct to try to help African farmers. They grow food organically by default, because they don't have money for chemicals. But they also don't have money for the organic certification process that would let them get better prices. So in 2005, I led a team of PhD students to try to implement a solution using mobile technology.

The idea was that at the point of sale there'd be a code on the product. You'd enter that in a mobile device, and up will pop the history and even pictures of the farm. But we realized a big flaw: farmers have to be trained to do the coding. This was not practical.

30%
of medicine sold in some countries is bogus

DATA FROM WORLD HEALTH ORGANIZATION

But picking up a fruit and wanting to know if it is organically grown is similar to picking up a pack of medicine and seeing if it was properly tested and certified. About 2,000 people die every day from counterfeit medicine. So we shifted the idea to pharmaceuticals.

In 2007 we set up a nonprofit organization in Ghana and rolled out a pilot, and the next year Nigerian health officials invited us to replicate the concept

Photograph by Nana Kofi Acquah

there. But we wanted to get to a point where a big company like Sanofi-Aventis would use us. We learned that most companies won't do business with an NGO, so in 2009 we launched mPedigree as a business.

You can send a free text message and get a reply in a few seconds verifying [that a medicine] is authentic. In addition, distributors and other middlemen can check the codes to verify that the supply has not been compromised. This helped reveal to a major Indian company that there was pilfering at a depot. Genuine antimalarial medicines would be replaced by counterfeits. The shady characters cannot get away with this anymore. If we had not stopped these leakages in the supply chain, they could have put thousands of patients at risk.

The system is used in Ghana, Nigeria, Kenya, and India, with pilots in Uganda, Tanzania, South Africa, and Bangladesh. We've got a relationship with many of the major regional—and a growing number of multinational—pharmas, including Sanofi-Aventis. In Nigeria our codes are on 50 million packs of antimalarial drugs alone, and we have just signed up two Chinese drug makers.

We are now expanding to seeds, cosmetics, and other businesses. And new applications are emerging that we hadn't expected, in the areas of logistics, supply chain management, and marketing. If you send an SMS to check authenticity, you've also given good information about exactly where and when a drug was sold—as well as provided a potential marketing opportunity to dispense coupons. We have built a major platform for supply chains in the developing world. But back at my school, of course, they still remember me as the activist." *—as told to David Talbot*

Screening prospective parents for recessive diseases could be the first big hit in clinical genomics.

BALAJI SRINIVASAN, 33

No company performs more genomic screens for medical use than Counsyl, a startup cofounded by Balaji Srinivasan. It scans the DNA of parents in 3 percent of all births in the United States. And yet when Srinivasan founded the company in 2007 with friends from graduate school and his brother Ramji, a mathematician who was pursuing an MBA, just about everyone was advising against it.

Their father didn't want them to go into medicine—which is somewhat surprising given that both of their parents are physicians. "He thought we should go into computer science," Balaji Srinivasan says. And colleagues at Stanford, where he teaches computational biology and statistics, said that if he was going to found a company doing genetic analysis, it should test for genes that might be implicated in common illnesses like heart disease and diabetes. But Srinivasan didn't want to get mired in the uncertainty over the complex ways genetics plays out in those kinds of diseases. With genome analysis only just beginning its march from research labs into doctors' offices and other clinical settings, Srinivasan figured a successful company would need to start with a more straightforward problem. That's why Counsyl began by testing only for recessive genetic diseases that are extremely well understood. "Anything that is a research question is premature for a business," he says. "Running a business is hard enough. Your fundamental science has to be rock solid."

Every year, three out of every 1,000 children are born with a genetic disease, such as cystic fibrosis, that did not afflict the parents—who most likely unknowingly carried a defective copy of a particular gene. If both parents carry a damaged copy, there is a 25 percent chance that their child will have the disease.

For around $99 (after insurance coverage), a couple's doctor can order a test from Counsyl, which will extract DNA from the parents' saliva or blood and sequence more than 100 different genes linked to recessively inherited diseases. If prospective parents both carry a broken copy of the same gene, then they can decide what to do: try to conceive naturally despite the risk, avoid conceiving, or use in vitro fertilization to conceive and have doctors screen out embryos that carry the double dose of defective genes. Counsyl is now screening the parents in about 120,000 births each year.

"Diagnostics is going to be completely reinvented by genomics," Srinivasan says. "And we are one of the first to get out there." *—Susan Young*

Portrait by Brett Affrunti

The cofounder of the security company CrowdStrike wants to help cyberattack victims strike back.

DMITRI ALPEROVITCH, 32

"After the investigation of Operation Aurora, the cyberattack on Google from within China that was revealed in 2010, I realized a completely new type of security strategy and technology was needed. I was leading research at McAfee and had been involved in investigations of criminal activity online, working closely with law enforcement. Aurora put us up against a nation-state, not a criminal. I was briefing the State Department as they crafted statements for Hillary Clinton to make publicly about the issue.

The online criminal problem was and is a big issue, but it pales in comparison to what nation-state attacks are doing to this country and our allies. Google has one of the best security teams on the planet, better than most government organizations, but they and many other companies with very good security practices were still getting hit. The problem was not the security widgets and technology they were using; it was the strategy. That's why I left McAfee to start CrowdStrike.

The industry and the government were using a passive strategy of trying to detect and block cyberattacks, and that doesn't work against an actor that's really determined. China's army is not going to give up and say, 'Well, we're out of the cyberespionage business.' What you really want is for a cyberattack to be very costly and risky, so it is used only rarely and only against really high-value targets.

Illustration by Golden Cosmos

Today security companies look for malware and software exploits, but they change constantly. And new ones are launched by the hundreds of thousands each day. At CrowdStrike we look for traces of the adversary and try to find out who the adversary is, what they are after, and what their tradecraft is. We also disseminate that information to enable collective action. It doesn't have to just be every company for themselves—they can band together and maybe join with government to put pressure on the enemy. We're starting to see that with some of the public disclosures about China, including ones I've done, leading the U.S. administration to start talking openly about the problem. That helped lead to Obama raising the issue at his summit with the Chinese president.

We use data from many sources to detect traces of adversaries and uncover everything we possibly can about them. Our customers can find out who is targeting them and how. We've showed how we could see the Chinese navy crafting spearphishing e-mails so we could warn targets before they even received one.

We call this new strategy 'active defense.' We respect the law, but we're in discussions with Congress about making changes because most relevant laws were written in 1986. We should enable the private sector to engage in self-defense in the cyber world, like we do in the physical world. Mall cops protect property the government doesn't have the resources to protect. A cyber-world equivalent could be allowing some licensed cybersecurity companies or individuals to take certain actions in defense of a network. That should not involve retaliations; hacking back to destroy the other guy's machine has no useful purpose and should be illegal. But if you see your data going to some other network, why can't you go into that network for the purpose of getting your data back, or take data off that machine to mitigate the damage? Allowing the private sector to do things like that can help companies make themselves a much less attractive target."

—as told to Tom Simonite

COURTESY OF DMITRI ALPEROVITCH

DATA FROM INSIGHT DATA SCIENCE

A startup called Kaggle tries to bring smart people to knotty problems.

ANTHONY GOLDBLOOM, 30

Anthony Goldbloom had been a data analyst when he founded Kaggle, a startup that helps companies outsource thorny problems to scientists like him. Yet when he was launching Kaggle, he relied on no data at all. He just figured it would work.

Back in 2008, Goldbloom was taking a break from his job as an analyst at the Australian Treasury. He had a reporting internship at *The Economist* in London—a position he snagged by winning an essay contest. While working on a story about predictive modeling, he spoke to people at large companies who told him how hard it was for them to make sense of data they had collected. Many companies didn't even have anyone who could do it.

That gave Goldbloom the idea: he would create a website where data scientists could compete to win cash in their spare time by solving such problems for companies. He didn't know much about programming, so he taught himself to code and built the website in his bedroom in Melbourne, Australia.

The site launched in 2010 with a contest that Goldbloom conceived and sponsored himself: $1,000 to the person who could determine most accurately how countries would vote in the annual Eurovision Song Contest. The BBC picked up the story, as did the tech news site Slashdot, which helped Goldbloom get the attention of institutions including the University of Pennsylvania and NASA. The insurance company Allstate offered $6,000 to whoever could come up with an algorithm for predicting the bodily-injury liability payments that result from accidents involving particular kinds of cars. An actuarial consultant in Australia took that prize.

$110,000
Common entry-level salary for a data scientist in Silicon Valley

As more and more companies began putting forward challenges, more and more data geeks joined Kaggle to vie for the opportunities. Now the user base exceeds 100,000, large enough to give the company another revenue stream: for a fee, it will match up companies with specific top performers.

"If you look around in the professional world, I can't think of another labor market that's truly meritocratic," Goldbloom says. "That's what we're trying to create: the better you are, the more you earn, the more work you get." *—Rachel Metz*

Photograph by Winni Wintermeyer

Visionaries 35

Q: How do you know whether a technology will stimulate connections between people?

A: It is not the inherent properties of a technology that determine its success. The key is to make sure that a particular technology meets the needs of those who wish to connect and that they find the technology so beneficial that they share it with the people around them. Design is about blending vision, technology, and beauty together to create tools that inspire passionate people to realize novel experiences. *—Danah Boyd, a social-networking researcher for Microsoft who was an Innovator Under 35 in 2010.*

COURTESY OF DANAH BOYD

Illustration by James Graham

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Stanford University

Mike Pellini
Foundation Medicine

If you want to use technology to make life better for people with autism and their families, the trick is to make the technology secondary.

JULIE KIENTZ, 33

Julie Kientz is an expert in human-computer interaction. But unlike many other computer scientists, she spends much of her time far away from a computer screen, figuring out the human side of the equation.

With her people-first perspective on technology, the University of Washington professor is at the forefront of an emerging idea: using relatively simple and common computing tools to improve human health. Kientz has created novel ways of helping people with sleep disorders and families with autistic children, such as a program that uses Twitter to help track key developmental milestones. "I think a lot of people in our area are like, 'I have a hammer, let's find a nail,'" says A.J. Brush, a senior researcher at Microsoft. "She's really thinking hard about what's the challenge, how to address it, how do I understand it."

Kientz's methods were formed in graduate school at Georgia Tech. Her doctoral advisor, Gregory Abowd, an expert in interactive computing and its use in health care, happens to have two sons with autism. His dedication to them inspired Kientz to investigate technology that could improve their care. But she didn't begin with the technology. She trained to be a therapist for autistic children and worked as one for a year and a half.

During sessions with an autistic child, a therapist might ask the child to point to a specific item, like an apple, from an array of objects; to imitate a word or gesture; or to copy the therapist's arrangement of blocks. Therapists use pen and paper to chart the child's ability to perform such tasks over time.

By working as a therapist and talking to others, Kientz identified problems with the paper-based method. One was that multiple therapists might need to review a child's records, but there was only one copy of the binder filled with hand-marked charts and notes. And with data points trapped on paper, there wasn't a good way to visualize broader trends or review negative blips in a child's otherwise positive progress.

1 in 88
Proportion of U.S. children diagnosed with autism

Kientz's solution was for therapists to use a digital recording pen and special paper that could digitize their writing. The change was unobtrusive to the therapist and invisible to the child. But notes and chart inputs made their way automatically into a database and were synched with video recordings of each session. This meant therapists could project progress graphs at meetings and pinpoint moments when a child didn't perform as well as expected. They could immediately access video from that moment in a therapy session; in one instance, therapists reviewed the video and agreed that they each had different standards for a "right" response. As a result, the child was given credit for mastering a skill and could move on to new challenges.

To Kientz, this human-centered use of computing was an antidote to frustrating internships she had held as an undergraduate at the University of Toledo, including

Photographs by Michael Hanson

one at Compaq in which she wrote debugging programs for a microchip. "It was really hard for me to see that connection between what I thought was the really impactful work and what I was doing on a day-to-day basis," she says, speaking in an office littered with geek ephemera such as a software engineer Barbie doll. (Kientz is married to Washington professor Shwetak Patel, an Innovator Under 35 in 2009.)

Through her work with autistic children, Kientz learned that federal health officials at the Centers for Disease Control and Prevention were looking for ways to spot signs of autism and developmental delays earlier in children's lives. When she dove in, interviewing parents and doctors, she realized that many families were already recording information the government was looking for, but their formats—snapshots, video, baby books—were hard to integrate with the conventional tracking data gathered by health professionals.

Kientz wondered if there was a way to combine the two kinds of data gathering. That led her to build a computer program called Baby Steps while she was still in grad school. It combined traditional baby-book functions (asking parents to post pictures of sentimental moments like a child's first trip to the zoo or to Grandma's house) with ways to record specific developmental milestones (is the baby making eye contact?). Baby Steps has been tested by a handful of families, and Kientz has a $500,000 grant from the National Science Foundation to explore whether the program could scale up to track milestones for any child in Washington state whose parents want to take part.

In this project, too, Kientz is deciding how to develop the technology only after first understanding how people might use it. She found that many Hispanic families in Washington don't have home PCs and are more likely to go online using phones. So she added phone-friendly features such as the ability to respond to

prompts from text messages or Twitter. For example, parents can follow a Twitter account that corresponds to the month their child was born. They might get a prompt that includes an age-appropriate milestone and a code so that their reply will get filed in the database. They might see:

> @BabySteps_Nov2012: Does your baby turn his/her head in the direction of a loud noise? #baby68

And then they could respond:

> @juliekientz: #Yes #Maya turns her head in the direction of a loud noise #baby68

For another project, Kientz is trying to make it much easier for people with sleep disorders to figure out what's wrong. Typically, they might have to go to a lab and get loaded up with electrodes for the night; later, they might sit in front of specialized equipment to test things like how their reaction time suffers when they're experiencing a sleep deficit. Kientz wanted to help people do all this themselves, at home. So she and collaborators from UW's medical and nursing programs built a prototype called Lullaby. It's a box with light, temperature, and motion sensors sticking out, wired to a computer and a touch-screen tablet. Patients wear an unobtrusive commercial gadget such as the Fitbit, which tracks exercise by day and sleep patterns by night. They don't have to fill out sleep logs, which are notoriously inaccurate. And to replace the lab exams measuring reaction times, Kientz's group developed a smartphone app that lets people test themselves.

Getting inspiration from actual human problems is leading Kientz and her graduate students in surprising directions—such as software they recently developed to help visually impaired people do yoga. "I feel like there's two routes you can go in research in my field," she says. "You can help a lot of people in a little way. Or you can help a few people in a big way." —*Jessica Mintz*

How he invented the smart watch.

ERIC MIGICOVSKY, 27

It's 2008. Eric Migicovsky is racking up kilometers every day on his sturdy blue *opafiets*—the no-nonsense bicycle beloved by Netherlanders. He's wheeling to classes at Delft University of Technology and other points in a city famous for its canals and blue-and-white pottery.

Life's great for the young Canadian engineer on a year abroad from Ontario's University of Waterloo. Except for one constant irritant. His cell phone never stops chiming, chirping, or vibrating. And prudence requires two hands firmly gripping the handlebars while veering through traffic between those picturesque canals.

"I read a survey that said the average person pulls out their cell phone 120 times a day," he says. "It occurred to me, 'Hey, what if I could just do it on my wrist?'"

Back in his dorm room, Migicovsky started fiddling with an electronic breadboard, an Arduino microcontroller,

275,000
Number of Pebble watches sold

PREVIOUS SPREAD: DATA FROM AUTISM SOCIETY
DATA FROM PEBBLE

Photograph by Winni Wintermeyer

and bits scavenged from a Nokia 3310. The mishmash became a precursor to a prototype—a "smart" wristwatch wirelessly tethered to a cell phone so that it could display e-mails, texts, and other basic notifications. "Plus tell time," he adds. "That still seemed a useful function for a watch."

He eventually transformed his toy into one of this year's most influential new technologies—the Pebble smart watch. Today Migicovsky runs a company in Palo Alto that has 31 employees and sells watches in Best Buy for $150 apiece.

Copycats have sprung up, and Apple looms as a likely competitor. Migicovsky is already responding by rethinking how people might use the Pebble. It could become less of a notification display and more of an app platform in its own right. Migicovsky recently released a software developers' kit intended to help other innovators devise applications solely for the watch—traffic trackers, weather predictors, exercise monitors, and games.

Getting here wasn't easy. Back at Waterloo, Migicovsky worked with a few pals on an early version of the watch—the first generation was called "inPulse"—in the garage of their rented house. In 2011, the project was accepted into Y Combinator, which provides modest seed money, advice, and critical contacts for technologists. That brought Migicovsky to California. "If I had to pick someone who will be the next Steve Jobs, it would be Eric," says Y Combinator founder Paul Graham.

But big investments remained elusive. As a long shot, Migicovsky posted Pebble on the fund-raising site Kickstarter. He thought he might reel in $100,000. "In 30 days, we raised $10.2 million," he says. "The smart-watch revolution had begun." *—Colin Nickerson*

COURTESY OF STEVE RAMIREZ

Illustration by Golden Cosmos

STEVE RAMIREZ, 25

An MIT grad student can find and even change memories in a mouse's brain.

"My parents came here from El Salvador in the late '70s to escape from civil war. They worked 100-hour weeks to give me and my brother and sister the opportunity of a better life. Years later, we have all these opportunities that we couldn't have dreamed of in El Salvador. I can't think of any better motivator.

The first seeds of my interest in the brain were planted between junior high and high school, when my cousin went into labor. While under anesthesia during a C-section, she went into a coma that she's been in ever since. The parts of her brain that are involved in producing consciousness and wakefulness were probably atrophied because they didn't get enough oxygen for just a short period of time. It instantly hit me: all it takes are these little lumps of tissue in your brain to atrophy, and now everything that makes you *you* is evaporated.

Because the seemingly ephemeral stuff of cognition is based on the physical stuff of the brain, we can go in and manipulate it and see how something as complicated as memory works. When you are thinking of a memory, only a subset of brain cells are active, and those cells are specifically representing that memory. We can genetically modify neurons to produce a sensor that detects when brain cells are active and then installs an on-off switch in them. The switch is a protein that allows us to control the activity of a cell with light.

So now we can emit light and reactivate cells and see whether a mouse exhibits behaviors that show whether it is recalling a certain memory. We place the animal in a box where it gets mild foot shocks from the floor. Naturally, if we later put the mouse back in the box, it runs to a corner in fear—it sits there and freezes, crouching and monitoring. Next, we put the mouse in a completely different box—different smells, sights, floor texture. In this new box the mouse has no reason to be afraid. But when we shine a light to reactivate the cells involved in making that fear memory, the animal immediately goes into that defensive posture. We can also shine light and reactivate pleasurable memories, such as a male mouse's memory of a female mouse.

In my second project, we tried to get a mouse to believe that it experienced something that it didn't. We called it Project Inception. First, we label the brain cells that are involved in the memory of a chamber—environment A—where nothing bad happens. The next day we put the mouse in environment B, where it gets foot shocks, and we simultaneously shine a light to reactivate the memory of environment A. Then, when you put the mouse back in environment A, it displays freezing behavior. It is recalling falsely that it was shocked in environment A even though nothing happened there.

We are pushing this technology as far as possible. Perhaps we can alleviate post-traumatic stress disorder by erasing the underlying traumatic memory. Or perhaps we can treat certain types of depression by updating negative memories with positive emotions. Science fiction can often inform reality." *—as told to Susan Young*

Analyzing newly available data about the intricacies of urban life could make cities better.

YU ZHENG, 34

Commuting through Beijing's apocalyptic congestion and pollution can test anyone's patience. But it has inspired big ideas from Yu Zheng, lead researcher for Microsoft Research Asia.

Take pollution. Most air-quality monitoring systems in China give a reading for an entire city. But air quality can vary greatly within cities depending on traffic, building density, and weather conditions. Zheng is taking that into account with a new project, U-Air. It analyzes current and past data from monitoring networks and many other sources to infer air quality at any given point in the city. Eventually Zheng expects the system to predict air quality one or even five hours in advance. That could help people figure out, say, when and where to go jogging—or when they should shut the window or put on a mask.

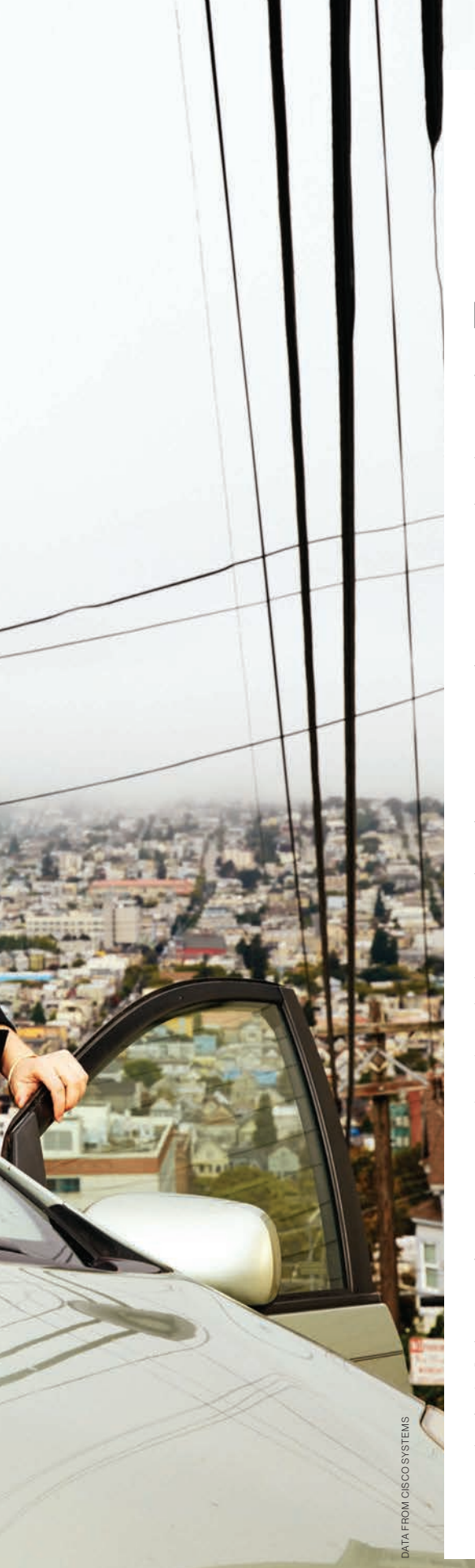
In an earlier project, Zheng and his team showed that online mapping services could recommend much better driving directions by taking gridlock into account rather than just finding the shortest routes. The trick was to learn from Beijing taxi drivers, who are forced to find the smartest routes every day. Zheng's group analyzed GPS data from 33,000 Beijing cabbies and figured out how to teach their subtle methods to a mapping program.

"When I see a problem," he says, "I feel passionate about trying to solve it."
—Michael Standaert

Photograph by Noah Sheldon

Schewel atop a hill near her office in San Francisco. Left: Zheng in hazy Beijing.

Photograph by Jake Stangel



DATA FROM CISCO SYSTEMS

LAURA SCHEWEL, 29

When Laura Schewel worked for an energy think tank and then the Federal Energy Regulatory Commission, she wanted to develop policies that would stimulate sales of electric cars. The trouble was, there wasn't comprehensive and reliable data about where and when people drive.

Typically, transportation experts construct predictive models to describe traffic patterns, or they conduct expensive surveys. Neither is particularly easy to do. "We have no idea what's happening on the roads. Just none," Schewel says. "When you compare that to what we know about what people watch on TV, it's absurd."

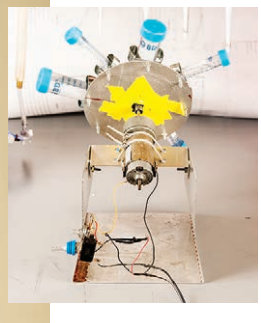
While in a PhD program at the University of California, Berkeley, she realized that people actually *were* revealing where they drive—to their cell-phone companies and GPS navigation services. She thought: what if I could get access to that data? It took a year to persuade companies to sell this valuable and sensitive information to a small startup she formed, StreetLight Data. The company, which aggregates and analyzes the signals from cell phones and dashboard GPS navigation systems, makes it easy for just about anyone to do what Schewel had long envisioned—see detailed maps of where, when, and how people travel through cities. With software that she and her team developed, Schewel can type in an address and find the demographics of the people who drive by or stop near that location. The system shows when they drive by, how frequently, and even what neighborhoods they're coming from. (Importantly, Schewel's algorithms analyze the movements of groups of these devices, rather than individual units. That means StreetLight's analytics can't be reverse-engineered to reveal any given individual's movements.)

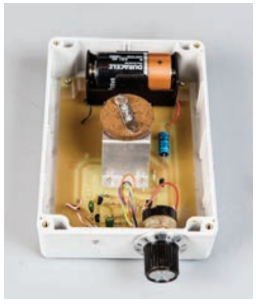
The information is appealing to customers far beyond the transportation-policy world. A medical office, an auto repair shop, and a small restaurant chain have been using StreetLight's software to help them decide where to open new locations and place billboards. And the nonprofit Oakland Business Development Corporation is using the software to demonstrate that people with disposable income often spend time in Oakland even if they don't live nearby. The data, the group hopes, will encourage small businesses and national chains to consider opening up shop in the city's struggling downtown, which has 400 vacant storefronts and office buildings in one square mile.

Schewel still believes she can make transportation more efficient. But rather than trying to persuade people to be green, she is focused on helping businesses—which have become "the most powerful behavioral-change force in America"—make it easy for people to do greener things. For example, if suburbanites can do some shopping near their offices in downtown Oakland on their commutes home, that might reduce the mileage they would otherwise have to drive. Naturally, Schewel backs up that idea with data: 30 percent of all miles driven in the U.S. are related to shopping. *—Jessica Leber*

25 billion

Number of devices that are expected to be connected to the Internet worldwide in 2015





Lowering the cost of basic biological research.

LINA NILSSON, 33

Above left: A rotator built by a member of the Tekla Labs team is designed to gently agitate biological samples.

Above right: A magnetic stirrer was designed by a Tekla Labs contributor in New Zealand.

The UC Berkeley bioengineering lab where Lina Nilsson worked as a postdoc is filled with the kind of expensive equipment necessary for advanced biological research. But many labs around the world don't have UC-level funding; they rely on hand-me-downs from well-heeled labs or simply do without. That makes it hard for them to find solutions to local problems such as the spread of malaria, never mind participating in the broader scientific enterprise.

Nilsson offers another option: DIY. As cofounder of Tekla Labs, an engineering collective on the Berkeley campus, she's curating and distributing open-source, do-it-yourself designs for the gamut of common lab gear. A shaker for separating excess dye from stained cells, for instance, can be made from a discarded record turntable. A centrifuge can be fashioned from a modified kitchen blender. A thermal cycler for amplifying DNA requires only light bulbs and thermometers. In the hands of scientists who historically have lacked access to equipment, such tools can be powerful engines of innovation—generally, Nilsson says, at about one-tenth the price of high-end commercial equipment.

"Great ideas are everywhere, but opportunity is not," she says. "My goal is to enable people to collaborate to solve global challenges." Along with her work at Tekla Labs, she serves as innovation director at UC Berkeley's Blum Center for Developing Economies, where she devises programs that bring together NGOs, scientists, engineers, and local organizations worldwide.

Nilsson was an outstanding, if uninspired, PhD candidate at the University of Washington in 2007 when, on a whim, she applied for a Bonderman Travel Fellowship, an open-ended program that gives students eight months to "come to know the world in new ways." She traveled to Asia and South America, where she visited local biology labs. "It completely changed everything about how I see the world," she says. "The discordance between the engagement of the scientists and their empty labs was jarring, and the vision for Tekla Labs started to emerge."

The challenge now is to make sure Tekla Labs' designs consistently yield devices precise and durable enough for serious research. After all, scientists everywhere need equipment they can rely on. *—Ted Greenwald*

Photographs by Winni Wintermeyer

New computing devices are inspiring new ways to input text.

PER OLA KRISTENSSON, 34

Per Ola Kristensson is making it easy, fast, and intuitive to input text on mobile devices. He helped invent the popular gestural text-entry method known as ShapeWriter, but that's just the beginning. Kristensson, a lecturer in computer science at St. Andrews University in Scotland, thinks gestures could be combined with speech recognition and even gaze recognition in a text-entry system that makes it easier to correct mistakes and enter unpronounceable information like passwords. "I'm interested in optimizing the flow of information from your brain into the computer," he says.

ShapeWriter lets you enter text by dragging a finger over the letters in a word. The software then stores the squiggle or shape that you make when you touch those letters as a stand-in for the word itself. The shapes for common words are easy to recall; any time you want to enter such a word, you can quickly reproduce its shape instead of pecking at the letters again. Practiced users can gesture-type in excess of 30 words per minute—blinding speed on the typical mobile device. The ShapeWriter app was downloaded more than a million times from Apple's App Store before it was bought by Nuance Communications in 2010. Now the technology is built into Android, where it's called "gesture typing."

Kristensson, who has a quick smile and an easy laugh, has always sought to fuse disparate fields of inquiry. Growing up in Sweden, he bucked an educational system designed to channel students into narrow specializations. He was drawn to computer science but couldn't bear spending four years studying nothing else. So he opted for cognitive science, which enabled him to study not only computer science but also linguistics, philosophy, and psychology. That combination launched him on the path to creating user interfaces that are fundamentally changing the way we interact with computers.

His work on tools for disabled people illustrates his approach to problem solving. Many people who can't speak and have very limited manual dexterity communicate by slowly typing words and prompting a computer to pronounce them. Their communication speed averages one or two words per minute. In such a laborious process, predicting the speaker's intent can greatly accelerate the task. This requires what is known as a statistical language model. "I was amazed to find that in 30 years of development of this kind of technology, no one had produced a good statistical model for the things these people need to say," Kristensson explains.

The main problem is the dearth of data from which to derive statistical relationships. You can't wiretap the computers used by large numbers of disabled people. So Kristensson came up with an alternative: ask people who are not disabled to imagine what they would say if they had to communicate by this method. He used Amazon's Mechanical Turk to crowdsource imagined communications—"Who will drive me to the doctor tomorrow?" and "I need to make a shopping list." Then he combed through Twitter, blogs, and Usenet for phrases that were statistically similar to the ones generated by Mechanical Turk. After several iterations, he had the tens of millions of phrases he needed to build a useful model.

These days, Kristensson is working on technology that supports super-fast typing: a gargantuan statistical language model that accurately interprets typed input despite large numbers of mistakes. He's also working on new ways to enter text in the absence of a touch screen or keyboard. Such technology will be necessary to make the most of wearable computing devices such as Google Glass, but it will have to work nearly perfectly to be of any benefit, given how frustrating a bad speech-to-text system can be. "In a few years, we'll have amazing sensors that will help us generate contextual information to create truly intelligent, adaptive interfaces," he says. *—Ted Greenwald*

Portrait by Brett Affrunti

Humanitarians 35

EVANS WADONGO

REBECA HWANG

CAROLINE BUCKEE

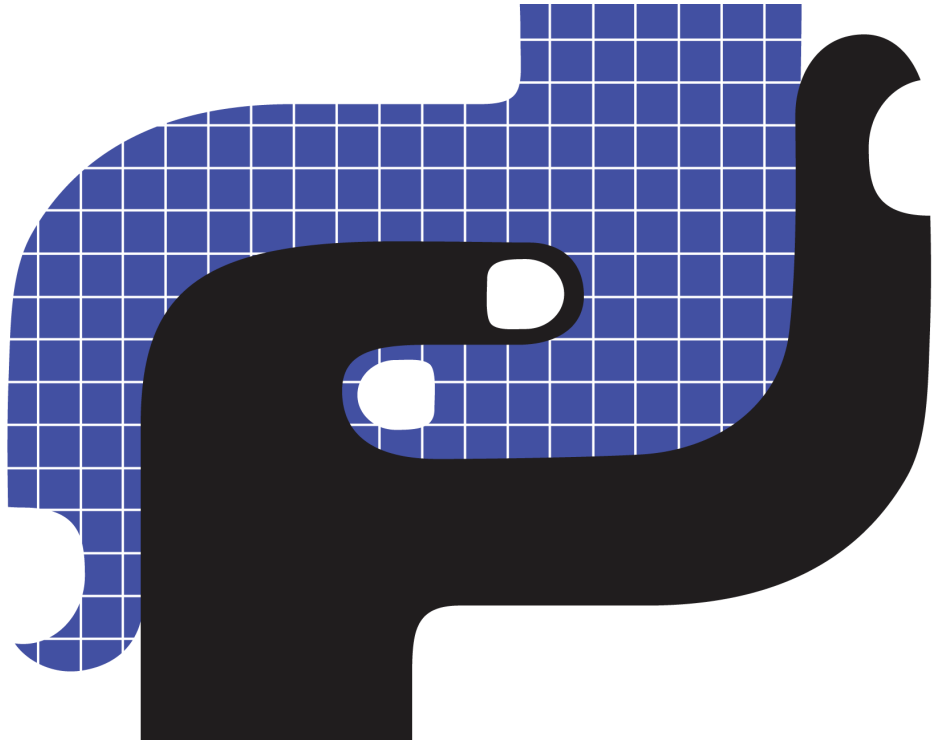
ENRIQUE LOMNITZ

AMOS WINTER

Q: How do you measure success?

A: I consider a project a success when I no longer have to work on it. I need to launch projects and find other people who are as excited about them as I am to nurture them. The results are vastly better than if I worked on a project by myself—good problems attract smart people, and they come up with richer and more nuanced solutions than I can on my own. By this metric, Global Voices [which aggregates the work of citizen-media bloggers in several countries] is one of the most successful things I've worked on. If I was hit by a bus, the project would thrive without me. Geekcorps, by contrast, didn't survive very long after my departure, which saddens me to this day.

—Ethan Zuckerman, selected as an Innovator Under 35 in 2002 for founding Geekcorps, a network of IT volunteers who helped fledgling businesses in poor countries.



COURTESY OF JOI ITO

Illustration by James Graham

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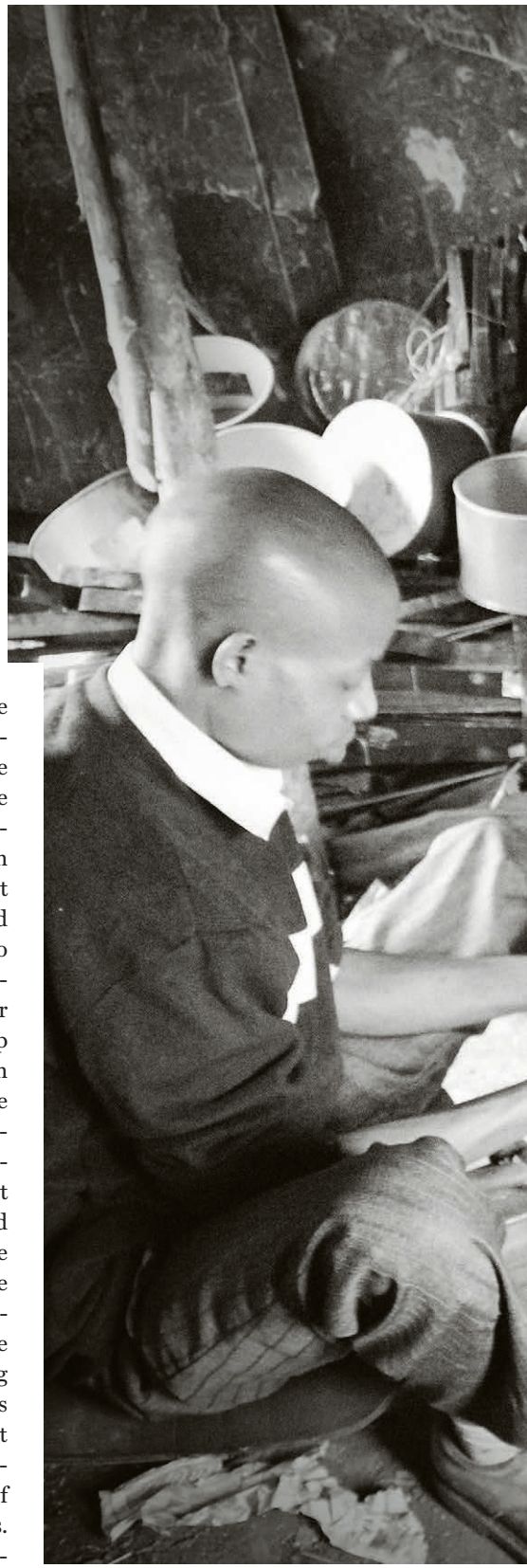


Growing up in Kenya, he strained to read by the dim light of a kerosene lantern. Now he's making solar-charged lanterns and using them to spur economic development.

EVANS WADONGO, 27

Kenya's unreliable electric grid doesn't reach Chumvi, a village about two hours southeast of Nairobi, where many of the 500 residents live in mud-walled, grass-roofed homes and eke out a living raising goats and growing kale, maize, and other crops. Yet an economic transformation is taking place, driven by an unlikely source—solar-charged LED lanterns. It can be traced to the vision of Evans Wadongo, 27, who grew up in a village much like this one.

As a child, Wadongo struggled to study by the dim, smoky light of a kerosene lantern that he shared with his four older brothers. His eyes were irritated, and he often was unable to finish his homework. "Many students fail to complete their education and remain poor partly because they don't have good light," says Wadongo, who speaks slowly and softly.

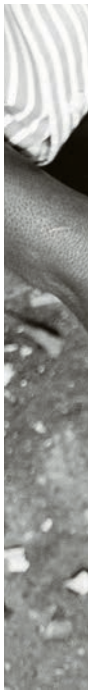
1.3 billion
Number of people worldwide without access to electricity

As a student at the Jomo Kenyatta University of Agriculture and Technology, he happened to see holiday lights made from LEDs and thought about what it would take to bring LEDs to small villages for general lighting. After taking a leadership training course from a nonprofit group, he designed a manufacturing system for portable LED lamps that could be recharged by sunlight. While many such lamps are already for sale commercially—and are increasingly making their way into villages in poor countries—Wadongo decided that his lanterns would be made in local workshops with scrap metal and off-the-shelf photovoltaic panels, batteries, and LEDs.

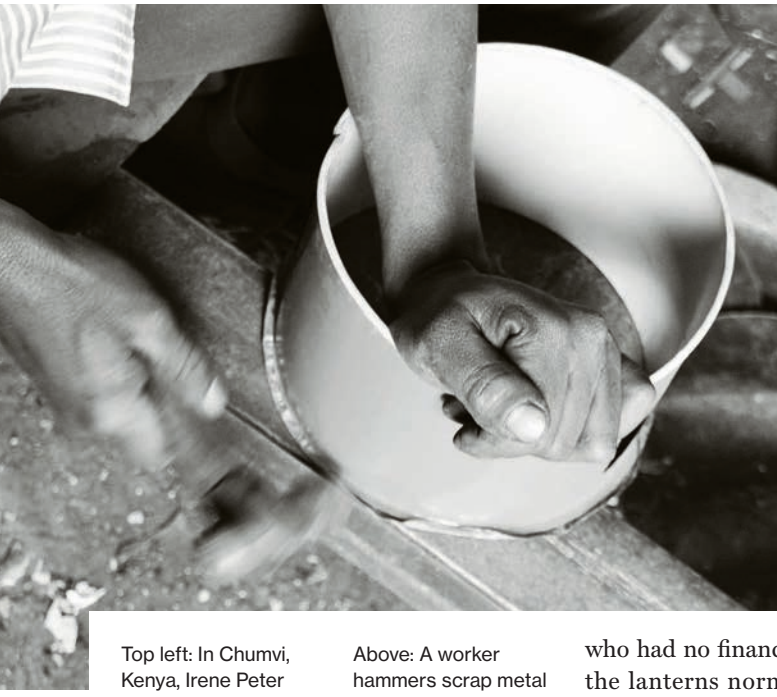
Wadongo feared that the technology would be less likely to take hold if the lamps were simply given to people

Wadongo (right) checks on the production of LED lamp housings in a workshop on the outskirts of Nairobi.

Photograph by David Talbot




MWANGA BORA



Top left: In Chumvi, Kenya, Irene Peter helps her son with English homework by LED light, which is cleaner and less expensive than kerosene.

Bottom left: Each lamp is stamped "Mwanga Bora," which means "Good Light" in Swahili.

Above: A worker hammers scrap metal to form a lantern housing.

Bottom right: Christine Mbithi, a mother of four in Chumvi, chops spinach by LED lamplight.

who had no financial stake in them. But the lanterns normally each cost 2,000 Kenyan shillings (about $23), which is out of many villagers' reach. So he uses donations (including proceeds from a recent exhibition of his lamps at a Manhattan art gallery, at which donors gave $275 apiece) to provide initial batches of lamps to villages. Residents are generally quick to see the value in the LED lamps because of the money they save on kerosene. Wadongo then encourages them to put the resulting savings into local enterprises.

The transformation in Chumvi began two years ago, when a woman named Eunice Muthengi, who had grown up there and went on to study in the United States, bought 30 lanterns and donated them to women in the village. Given that the fuel for one $6 kerosene lamp can cost $1 a week, the donation not only gave people in the town a better, cleaner light source but freed up more than $1,500 a year. With this money, local women launched a village microlending service and built businesses making bead crafts and handbags. "We're now able to save 10 to 20 shillings [11 to 23 cents] a day, and in a month that amounts to something worthwhile," says Irene Peter, a 43-year-old mother of two who raises maize and tomatoes. "Personally, I saved and got a sheep who has now given birth." She also got started in a business making ornaments and curios.

As profits rolled in from new enterprises like these, the women who got the original 30 lamps gradually bought new batches; according to Wadongo, they now have 150. "Their economic situation is improving, and this is really what keeps me going," he says, adding that some people are even making enough to build better houses. "The impact of what we do," he says, "is not in the number of lamps we distribute but how many lives we can change."

Wadongo is also changing lives with the manufacturing jobs he is creating. In an industrial area of Nairobi, banging and clanking sounds fill a dirt-floored shack as two men hammer orange and green scraps of sheet metal into the bases of the next batch of lamps (soon to be spray-painted silver). Each base is also stamped with the name of the lamp—Mwanga Bora (Swahili for "Good Light"). The three men in the workshop can make 100 lamp housings a week and are paid $4 for each one. Subtracting rent for the manufacturing space, each man clears $110 per week—far above the Kenyan minimum wage.

Some of the lamps are completed in the kitchen of a rented house in Nairobi. Three LED elements are pushed through a cardboard tube so they stand up inside the lantern's glass shade. The LED elements, photovoltaic panel, and batteries are sourced from major electronics companies. Overall, the devices are rugged; the steel in the housing of the lantern is a heavy gauge. If a housing breaks, it can be serviced locally—and the electronic parts are easily swapped out.

Wadongo now heads Sustainable Development for All, the NGO that gave him his leadership training, and he is focusing it on expanding the lamp production program. It has made and distributed 32,000 lamps and is poised to increase that number dramatically by opening 20 manufacturing centers in Kenya and Malawi. Wadongo says that teams in those centers will independently manufacture not only the lamps but "any creative thing they want to make." *—David Talbot*

PREVIOUS SPREAD: DATA FROM INTERNATIONAL ENERGY AGENCY
JOE MATHAI (PETER, MBITHI). DAVID TALBOT (LAMP, WORKSHOP)

Many innovations can't happen without the right connections.

REBECA HWANG, 33

Rebeca Hwang thinks the insularity of Silicon Valley stifles innovation. To fix this, she's become what she calls a mega-connector, trying to make it easier for entrepreneurs anywhere to find opportunities.

Hwang has spent the past few years as CEO of San Francisco–based YouNoodle, which helps run competitions among technologists and entrepreneurs. For example, the Intel Foundation used YouNoodle's online service Podium to run business-plan competitions in Latin America and Europe. The government of Chile used it to solicit requests for funding from entrepreneurs.

It's one of many ways Hwang, who was born in South Korea and raised in Argentina, has tried to link far-flung people or ideas. As an MIT undergrad she studied chemical engineering; at Stanford she cofounded the Cleantech Open business accelerator and pursued a PhD in social-network theory before joining YouNoodle.

"I could have chosen to just go the academic route; I could have just done entrepreneurialism," she says. "But I think I excelled most at the intersection—bringing all these parties together and coming up with solutions that have several perspectives."

—Rachel Metz

Cell phones can become a weapon against disease.

CAROLINE BUCKEE, 34

In her work as an epidemiologist, Caroline Buckee thinks a lot about malaria—but the same could have been said when she was six years old. "There's a story my dad tells about my dinnertime conversation when I was little," she says. "I often used to say things like, 'What's your favorite disease?' And it turns out my favorite was malaria."

The obsession never quite waned, because malaria is caused by "a fascinating organism," says Buckee, now an assistant professor at the Harvard School of Public Health. "It's really a shape-shifter. It evolves very quickly to anything we throw at it. It's a clever parasite." And most disturbing, she says, even though it is treatable and preventable, malaria is still among the biggest infectious-disease killers of children.

In 2006, during a research trip to Kenya, it occurred to her that work her husband, Nathan Eagle (himself an Innovator Under 35 in 2009), was doing with data about cell-phone use might be employed in the service of malaria prevention. What if, Buckee wondered, location data from cell phones were used to intuit a malaria outbreak's point of origin? Locals might then be warned via text messages to avoid the area or use bed netting. Health officials could know where to concentrate their mosquito-spray efforts.

Indeed, when Buckee pored over data from 15 million Kenyan cell phones, telltale patterns emerged. People who had made calls or sent messages through a certain phone tower were extremely likely to later visit a region near Lake Victoria where malaria wound up erupting in force. The area near that tower was probably the original hot spot—and thus where health officials should focus.

655,000
Estimated deaths from malaria worldwide in 2010

Buckee and her colleagues are still figuring out the best way to use this data (which was one of *MIT Technology Review*'s 10 Breakthrough Technologies of 2013). But the results so far give her confidence that she's found a crucial tool for her work in epidemiology. "The ubiquity of cell phones is really changing how we think of diseases," she says. *—Timothy Maher*

DATA FROM WORLD HEALTH ORGANIZATION

Portrait by Brett Affrunti • Photograph by Adam DeTour

A design student returned to his native Mexico City after college in the United States to help the megalopolis overcome its water crisis.

ENRIQUE LOMNITZ, 30

"When I was at the Rhode Island School of Design, my friend and I worked on a project to develop sustainable housing for low-income sectors of Mexico City. We realized that access to water was getting worse, whereas telephones, pavement, security—all the other infrastructure—was improving. We became convinced that the city needed to develop an alternative way to get water.

About 70 percent of Mexico City's water comes from the aquifer, and the water table drops something like a meter a year—it's super stressed. The actual ground of the city sank more than 10 meters in the 20th century due to extraction of water. About 30 percent of the water is pumped 1,000 meters uphill from 150 kilometers or so away, which is just insane. They say it consumes as much electricity as the city of Puebla [which has 1.5 million people], and it takes up a major portion of the city's budget. But by harvesting rainwater, you could achieve a massive systemic shift. Even with small cisterns, people could go for six months of the year just with rainwater, which is abundant during the rainy season.

10 million
Number of people in Mexico who lack access to clean water

Our initial challenge was to make a relatively low-cost system, which gives water of a certain quality using a simple filtration system, that you can retrofit onto existing houses. We interviewed this one woman who lives in one of these mountainside neighborhoods on the southern periphery of the city. My friend and I put one system with a cistern up at her house using about $1,000 out of our own pockets. Then I moved pretty much across the street from her and we started putting rainwater harvesting systems in the neighborhood, building this concept. Our rainwater systems hook up to cisterns, pumps, and the header tanks on roofs that feed water by gravity into a house.

We've installed close to 1,300 systems in four years, but we've been through many iterations, and it's not something I ever see ending. We sell the systems; we're starting to be able to offer philanthropic microloans, we have government funding, and we get donations, mostly corporate donations. We need to fish in a lot of ponds." *—as told to Martin LaMonica*

COURTESY OF ISLA URBANA
DATA FROM NATIONAL WATER COMMISSION OF MEXICO

"It bugs me sometimes the way people think about technology for the developing world," says Amos Winter. "People think you can cobble it together from scrap parts, and undergrads can make it in a semester, and you can give it away for free. And none of that is necessarily true."

Winter is lately renowned for having created a wheelchair specially tuned to the needs of people in poor countries: sturdy enough for uneven terrain, nimble enough to negotiate the indoors. The idea emerged when he was an MIT grad student visiting Tanzania in 2005; within three years he'd worked up a prototype to take back for a test run. That's when his real education began. The chair was too heavy, users complained. It was too unwieldy to use inside. It wasn't stable enough on hills.

Winter learned an important lesson: "We can't just sit in this lab and make something on the lab bench and bring it to Tanzania and think it's going to work," he says. "It never works that way."

Now a professor of mechanical engineering at MIT, Winter applies that lesson to other projects. In a cluttered back room of his lab, he holds aloft a prosthetic leg and points to a locked metal coupling, which is, he says, the most commonly used knee joint in poor countries. "When you walk with this, you walk with a peg leg," he says. "In most developing countries there's a stigma associated with disability, and walking around with this is a clear sign that you're disabled."

Winter's goal is to make a low-cost leg that copies the natural gait of $50,000 advanced prosthetics. "A lot of it just comes down to 'Let's make something that performs as good as the rich-world technology, for a small fraction of the price,'" he says. That typically means cheaper materials, but it's not quite as simple as that. Those new materials need to be readily available in the country where the product will be made. They are likely to weigh less, or more, and behave differently under stress—producing a whole new set of engineering challenges. Winter describes, with great enthusiasm, the massive amount of calculation required to get the torque of the knee just right at every point in the walker's stride.

He's more than a year away from a working prototype, but he has already asked potential users in India what they might hope to do if they had a better leg. "The highest-ranked thing was to be able to sit cross-legged," he says. "With existing prostheses, you just don't get the rotational twist you need. And I never would have guessed that. This is why it's so important to get there on the ground."

Winter's lab has the feel of a clubhouse; his students cheerfully mill about, and models and prototypes litter every tabletop. At the back end is a machine shop strewn with aluminum chips. You wouldn't gather, at a glance, that these prototypes might touch anyone outside this room, but Winter talks about the "monumental potential for impact." He gestures toward a mockup featuring a couple of plastic bins and some tubing: an experimental model of a drip irrigation system. To compensate for the often spotty power grids in poor countries, Winter's version would use only a tenth of the pressure required by conventional systems and thus consume much less electricity. His system relies on an engineering trick involving plastic tubing that mimics the action of bronchia in lungs.

800 million
Subsistence farmers worldwide

"If we crack this, and I think we're going to, this is a billion-person problem," he says. "Megafarms in Iowa can use this technology as well." —*Timothy Maher*

Some problems aren't apparent until you ask.

AMOS WINTER, 33

Top left: Winter, with welding torch, builds prototypes by himself and with graduate students.

Top right: A knockoff of the popular Jaipur prosthetic foot. Winter is trying to design a better foot.

Bottom left: The single-axis, exoskeletal prosthetic knee forces those who use it to walk with a peg-leg gait. Winter wants to make a low-cost leg that affords a more natural stride.

Bottom right: The speed control of the lathe in Winter's lab.

Opposite page: Winter and the Leveraged Freedom Chair, developed for people in poor countries.

Photographs by Christopher Churchill

DATA FROM AMOS WINTER

Pioneers

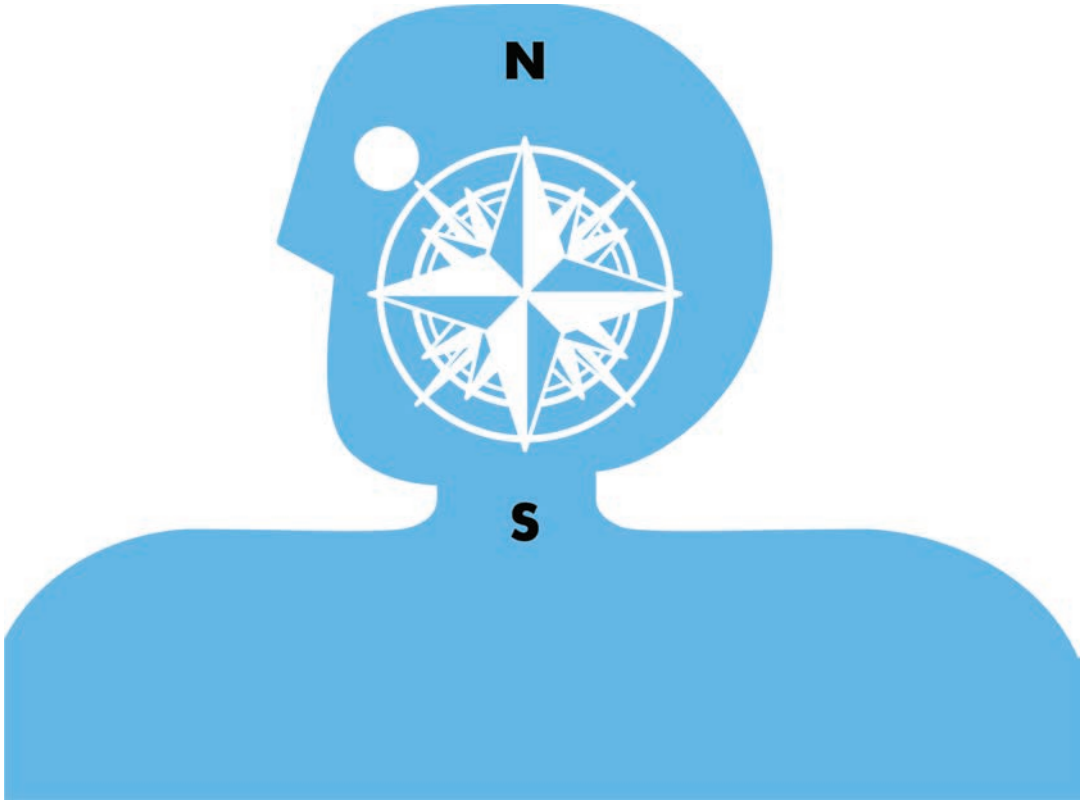
35

Q: What is the greatest unknown in science?

A: The greatest unknown today is the physical basis for life. Biology is transforming from a descriptive science to an information science, and it is yet to be determined whether it will become a true physical science.

— Stephen Quake, an Innovator Under 35 in 1999, who has played a leading role in the creation of microfluidics.

JOHN DABIRI
FENG ZHANG
KUNIHARU TAKEI
ROOZBEH GHAFFARI
LIANGFANG ZHANG
LESLIE DEWAN
BOWEN ZHAO
XIAOLIN ZHENG



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Theme 2013
Disruption and Innovation: Game Changers Powering the Global Market

Keynote speakers of the Forum

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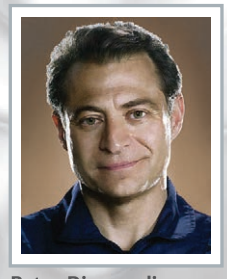
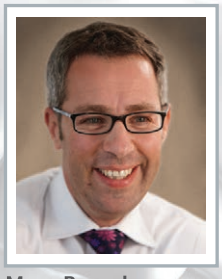
Global Ambassador, Cellular, Telecommunications, Internet Association (CTIA)



Peter Diamandis
Founder, X-Prize Fund; Co-founder, Singularity University



Mene Pangalos
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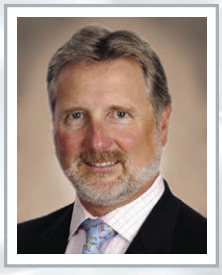
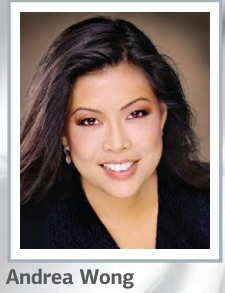
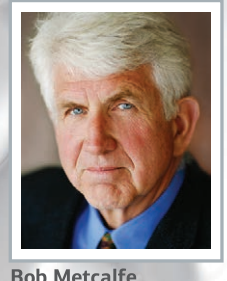


Steven Burrill
Founder, CEO, Burrill & Company

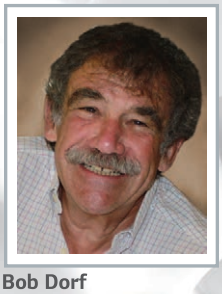


Andrea Wong
President, International Production, Sony Pictures Television (SPT)



Bob Metcalfe
Professor of Innovation, University of Texas at Austin

Dani Essindi Behrendt
Strategic Alliance Lead, Honda Silicon Valley Lab



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Serial Entrepreneur; Co-author, "The Startup Owner's Manual"

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How is a wind farm like a school of fish?

JOHN DABIRI, 33

Caltech professor John Dabiri uses his engineering expertise to try to understand how animals move in their natural environments. While researching the swimming patterns of fish, he recently came to a surprising insight: the way we're thinking about wind power—specifically, the design of wind farms—is wrong.

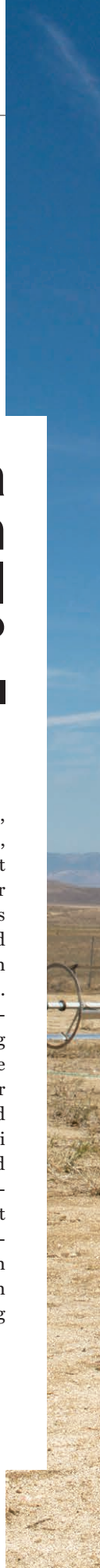
Conventional wind farms are designed to minimize the turbulence caused by interactions between turbines. That creates an obvious problem, says Dabiri: "You space them out as far as possible. If you're talking about a wind turbine that has a 100-meter diameter, then you're talking about as much as a mile between wind turbines. That's a lot of space that could be used to generate electricity, but can't be because of these turbulent interactions."

Dabiri thought of a solution while researching how fish form schools to minimize drag as they move about. "Fish can reduce the amount of energy that they use if they swim in certain coördinated arrangements as opposed to swimming alone," he explains. "In fact, fish in large schools form precise, repeating patterns that allow them to move most efficiently. There's some basic fluid-mechanics theory that you can use to explain why that might be the case. Jotting down the math for urban wind-turbine analysis, there was sort of a eureka moment where I realized that the equations were exactly the same equations that explain fish schooling.

"Why not use how fish form schools as a starting point for understanding how to design wind farms?" asks Dabiri. "We began to use the same tools that were used to determine the optimal configuration for fish schools to optimize the wind farm. We looked at an arrangement that's been identified as optimal for fish, and we found that if we, in our computer models, arranged our wind turbines exactly in the same kind of diamond pattern that fish form, you get significant benefits in the performance of a wind farm."

To maximize that performance, Dabiri would use vertical wind turbines, which have been around for years but are much less common than the familiar horizontal-axis turbines. Vertical turbines can perform better when they are packed together—at least if they are arranged in the optimal pattern Dabiri discovered. That raises the possibility of redesigning wind farms to increase the amount of power they produce and lower the cost. Dabiri says the turbines could be squeezed into existing wind farms so that they produce more power without taking up any more land. It's a solution that could greatly reduce the drag on an industry that often seems to be swimming upstream. *—Kevin Bullis*

60,000
Megawatts of wind-power capacity in the United States



Photograph by Misha Gravenor

Genomic research may finally help dispel the ignorance shrouding many types of mental illness.

FENG ZHANG, 31

"There have been a lot of taboos about psychiatric diseases," says Feng Zhang. "People would think depressed people are not mentally strong enough. But that's not true. In this and the next decade, we will learn much more about the mechanisms that lead to these neurological problems. And that will change our way of interacting with these people, and it will also change how we can treat them."

Zhang is an assistant professor at MIT and one of only 11 core faculty members at the Broad Institute, a leading center of genomic research. He's spent much of his brief but impressive career developing tools to understand how the brain functions, including what goes wrong in people with mental illnesses. As a graduate student at Stanford, he played a key role in developing optogenetics, which uses light to affect the behavior of living animals by controlling specific neurons; he then used the technique in mice to pinpoint brain cells that play a role in depression.

But truly understanding the genetics of mental illnesses will mean identifying the mutations causing the abnormal behavior. After getting his PhD, Zhang invented two new ways to "edit" animal genomes that were far cheaper and more effective than the existing technology. One method in particular, called CRISPR, promises to change how genomic engineering is done. It allows researchers to precisely snip out a short sequence of DNA so that they can substitute other genetic material or simply delete the sequence.

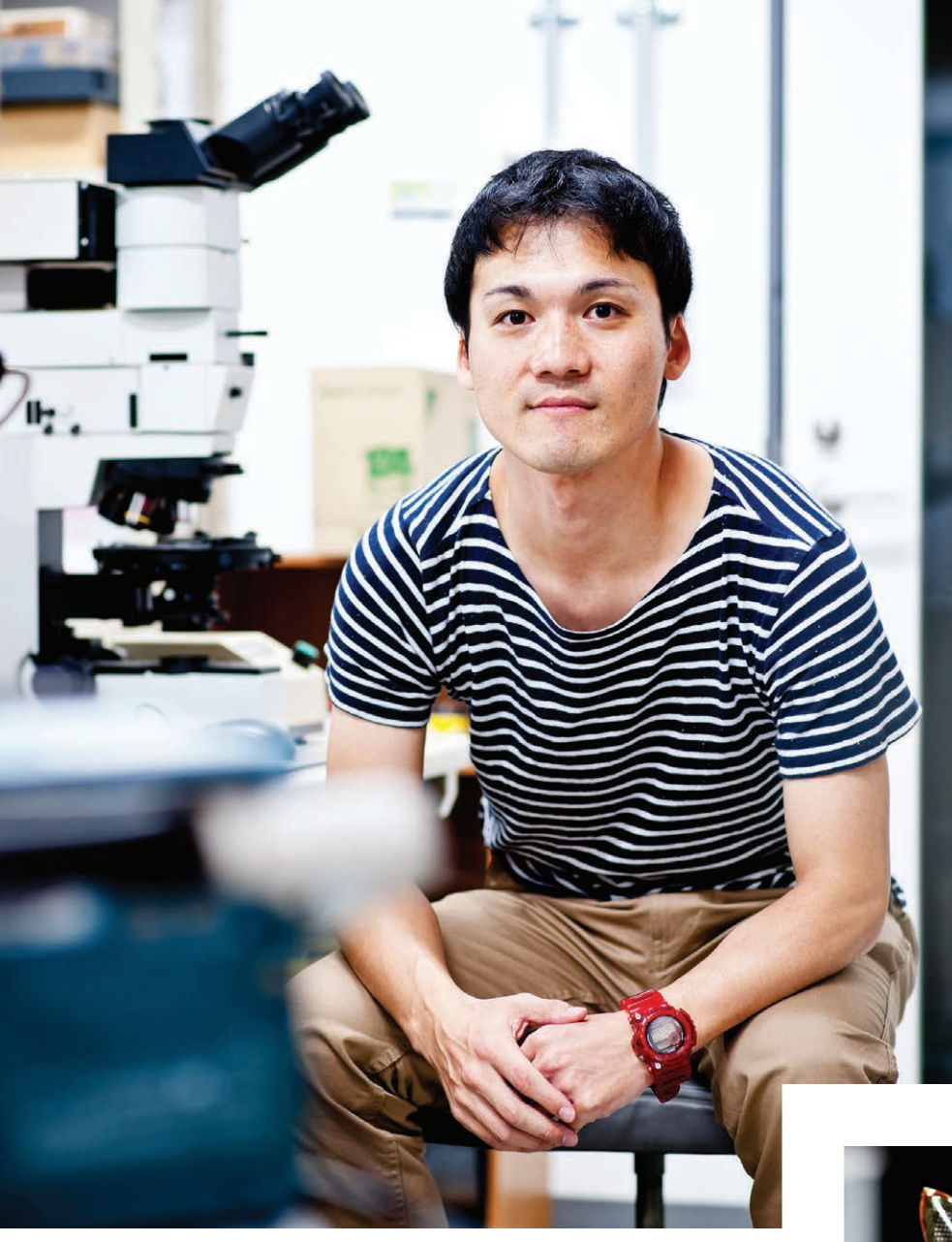
By inserting genetic mutations that others have linked to autism and schizophrenia into human stem cells that mature into neurons, Zhang is able to create brain cells with the specific genetic errors linked to those conditions. This makes it possible to study the abnormal cells directly: Do the neurons look different? Are there biochemical clues to what is going wrong? He has also engineered mice with the mutations to study how the changes affect behavior. Such research could not only help identify the causes of the disorders but suggest ways to identify and test drugs to treat them—and his genome-editing tools may even one day provide a way to "fix" the mutations.

Zhang has been interested in ways to "repair" diseases since he was in high school in Iowa, when he spent every afternoon working with a medical researcher at the Human Gene Therapy Research Institute, a part of Methodist Hospital in Des Moines. Though the gene therapies available at the time turned out to be too risky for widespread use in humans, Zhang never gave up hope of finding ways to directly fix the genetic mutations behind many diseases, using the increasing capabilities of genomic engineering. These days, bolstered by the success of his editing tools and other genomic advances, he is working to translate the technology into actual human therapies and exploring opportunities to start a company.

—David Rotman

PREVIOUS SPREAD: DATA FROM U.S. DEPARTMENT OF ENERGY

Portrait by Brett Affrunti



A novel fabrication step for nanomaterials could lead to fast, energy-efficient flexible electronics.

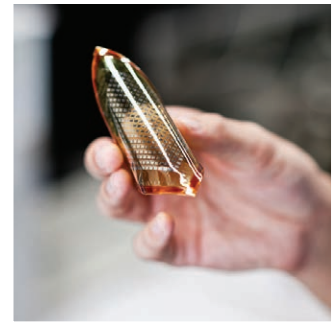
KUNIHARU TAKEI, 32

Kuniharu Takei is exploring new ways of printing different kinds of nano devices.

An early prototype of electronic skin uses a plastic substrate and carbon nanotubes.

Innovation: Kuniharu Takei, a professor at Japan's Osaka Prefecture University, has led the development of cheap and robust methods for "printing" uniform, ultrathin patterns of different types of nanoelectronics on a wide range of surfaces.

Why it matters: Nanoscale components made of materials other than silicon could lead to more versatile, less expensive electronic devices. Transistors made from so-called compound semiconductors, for instance, could be up to twice as fast and 10 times as energy efficient as silicon transistors. Takei's goal is to build circuits and sensor networks that simultaneously exploit the properties of several materials, each chosen because it offers a specific advantage. Nanomaterials made of compound semiconductors could be used to add high-speed radio-frequency components and efficient light emitters to silicon chips. But there is not yet a way to cheaply and reliably add such nanoscale components. Existing strategies involve highly specialized procedures for growing these materials on silicon or attaching them to silicon wafers; such methods are expensive and may not be practical for manufacturing. Printing processes like Takei's could be an attractive alternative.



Methods: In the process he uses to print compound-semiconductor nanomaterials, Takei grows thin films of the chosen material on a suitable substrate, uses a lithography technique to create strips in the material, and releases the patterns from the substrate with a chemical etchant. He can then transfer the nanomaterial to a range of new surfaces, including silicon wafers and bendable plastics, by using a silicone rubber stamp that picks up the material and prints it.

Next steps: Takei's printing methods could be used to produce electronic devices that exploit the properties of multiple materials. For example, he says, organic light-emitting diodes could be combined with transistors made of inorganic nanomaterials to make low-power, bendable displays. He's now working on a smart bandage that would be able to sense and respond to things like glucose level and skin temperature.

—Mike Orcutt

Photographs by Keith Tsuji/Getty

Inspired by the courage of his younger brother, MC10's cofounder is finding ways to create novel electronic devices that improve human health.

ROOZBEH GHAFFARI, 33

When Roozbeh Ghaffari was five years old, his only sibling—a brother named Soran—was born three months prematurely. A few things would eventually emerge about Soran: he was blind and mildly intellectually impaired, he had remarkably acute hearing (and perfect pitch), and he was his older brother's best friend, superfan, and inspiration. As the elder Ghaffari became an expert in the science and technology of body-machine interfaces and devices that can be integrated into the body (he now leads advanced technology development at MC10, a startup in Cambridge, Massachusetts), Soran remained physically at home in Los Angeles but frequently at his brother's virtual side, standing by for nightly telephone updates and reading up on his work using text-to-speech software.

Indeed, while Roozbeh Ghaffari's lifelong interest in the merger of biology and engineering was shaped partly by his parents—his mother is a microbiologist and his father an architect—it was inspired mainly by his brother, whose blindness was caused by retinal damage from excessive oxygen exposure in the neonatal intensive care ward. "What I found was that my goals were all driven by him," he says. "I wanted to work on the retinal implant project at MIT, right from year one as an undergraduate."

He didn't succeed at finding funding for that daunting challenge. But as a graduate student in the Harvard-MIT Division of Health Sciences and Technology, he shifted to another critical problem, this time inspired by his brother's sharp hearing rather than his deficient eyesight. Ghaffari's goal was to unravel the mysteries of the cochlea—that "biological black box with thousands of moving parts in a fluid" that transforms vibrations in the inner ear into nerve signals. "How do we hear with such remarkable sensitivity?" he asks. "How can we process both the roaring sound of jet engines and the sound of pins dropping?"

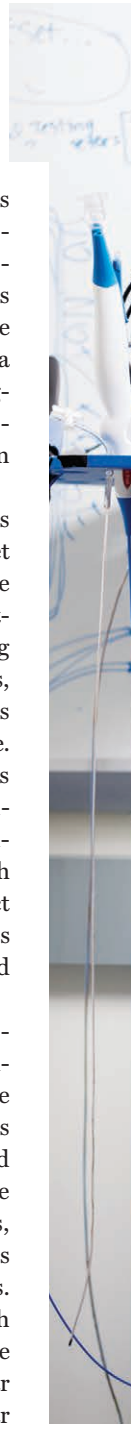
Focusing on a cochlear structure called the tectorial membrane, he managed to build a system that could measure what the structure was actually doing. "It supports a traveling wave of energy that can propagate along the cochlea. That hadn't been known before," he says. And this could help explain how the human ear can detect both very loud and very soft sounds, as well as a wide range of pitches.

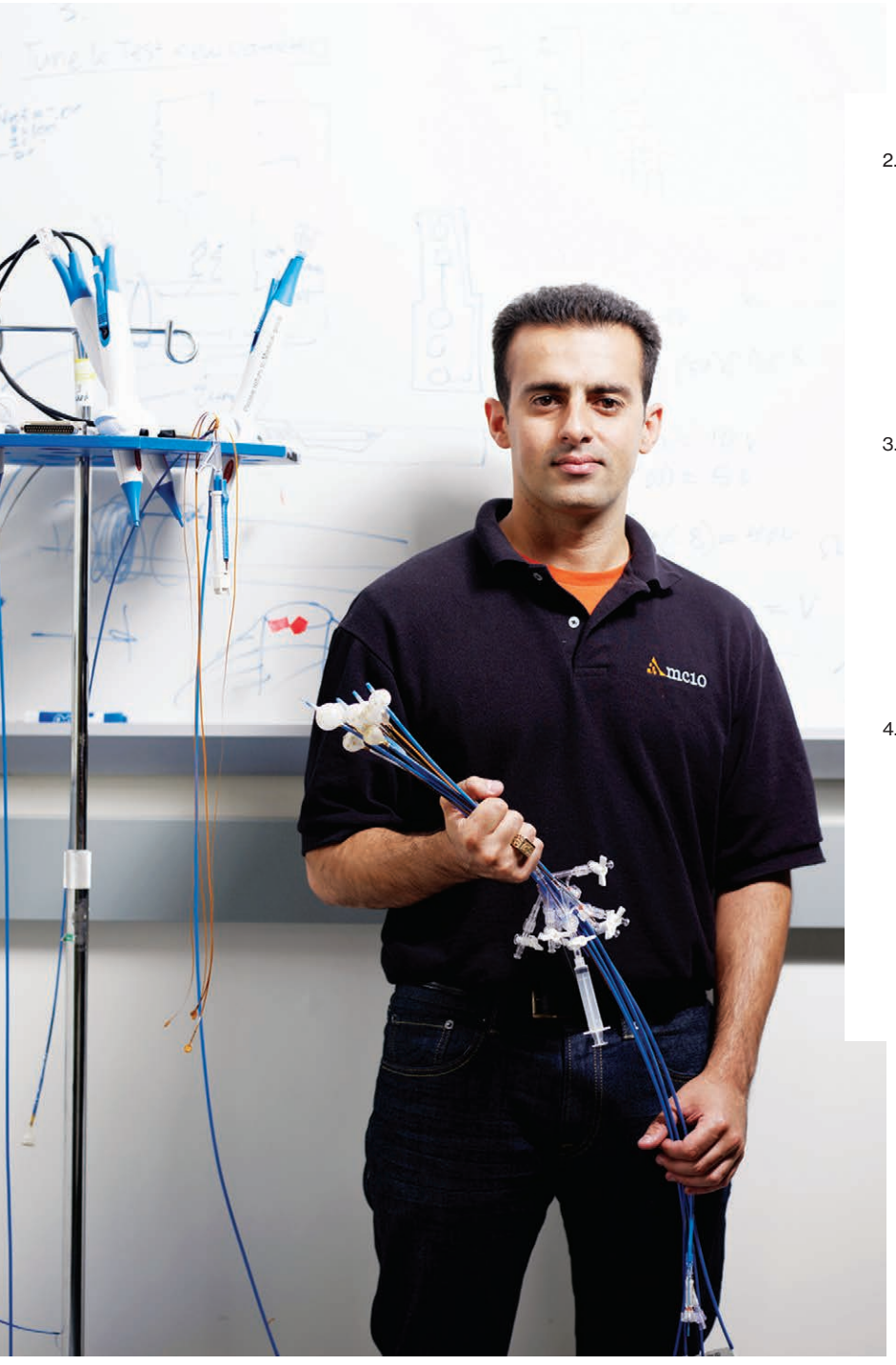
After taking a Harvard Business School class focusing on commercializing science, and meeting venture capitalist Carmichael Roberts and postdocs in the lab of Harvard chemist George Whitesides, Ghaffari helped develop a business plan for a company called Diagnostics for All, which is commercializing paper-based diagnostics invented in Whitesides's lab.

Next, with Roberts and Whitesides serving as the matchmakers, Ghaffari met John Rogers, a materials scientist at the University of Illinois. Rogers was fabricating stretchable electronic devices using polymers and ultrathin semiconductors, such as silicon. But the technology was looking for an important problem to solve. So in 2008 Ghaffari was brought on as cofounder of MC10. The founders considered what kinds of flexible or stretchable products they might enhance with electronics (they even considered contact lenses), but within a couple of months they had settled on balloon catheters and health-monitoring skin patches.

Today, the devices under development add electronics and sensors to balloon catheters. Existing versions of these devices are snaked into coronary arteries and inflated to compress accumulated plaques that can block blood flow. The new versions can, among other things, sense misfiring cardiac tissue that causes irregular heartbeats called arrhythmias. They can even ablate tiny patches of such tissue without harming the healthy tissue nearby. As always, Soran is eager to hear all about it. "He'll go look up 'ventricular tachycardia' and grill me night and day: 'What is this disorder? What are you guys doing?'" Ghaffari says.

Someday Ghaffari may yet build what his brother needs: a bionic replacement for his damaged retina. In the meantime, he is finding new ways to create other devices that promise to help others. While its catheters still need regulatory approval, MC10





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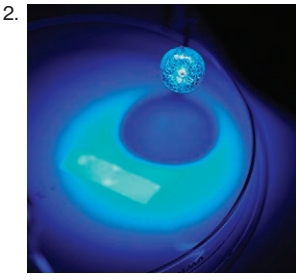

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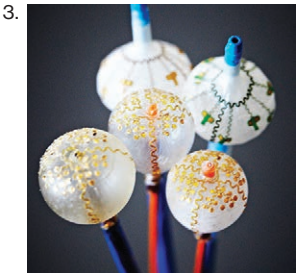

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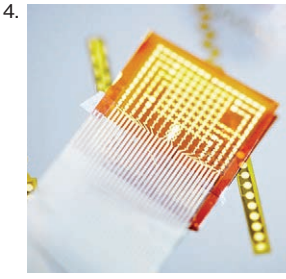


1. Roozbeh Ghaffari holds cardiac balloon catheters that use arrays of electronics.

2. Ultraviolet light is used to affix the sensors to the catheters.

3. The stretchable sensors and actuators embedded in the balloon catheters help diagnose and treat problems.

4. A chip with electrodes and temperature sensors can be laminated on a heart.

has launched a thin $150 cap that athletes, such as football or hockey players, can wear inside their helmets to indicate the severity of blows to the head. By lighting up red, yellow, or green LEDs on the cap, the technology could indicate whether the wearer might have suffered a worrisome head impact.

When Soran comes to Boston, Ghaffari brings him to the MC10 lab and lets him hold and feel the electronic skullcaps and the instrumented catheters, with their intricate patterns of ultrathin, stretchable sensors. But even when Soran is home in Los Angeles, Ghaffari says, the following question he inspires is in the back of his mind every day: "How can we turn technology into something useful that integrates with the human body?" And every evening, Soran is on the other end of the line, helping him answer that question. *—David Talbot*

Photographs by Christopher Churchill

A nanoengineering scheme to make drugs more effective by fooling the immune system.

LIANGFANG ZHANG, 33

PROBLEM: Scientists have worked for years to increase the longevity of targeted drugs, which promise to deliver treatment to a specific tissue within the body. These targeted treatments require new drug carriers such as polymers that are designed to evade the immune system. But too often, these carriers are destroyed before the drug can effectively target tumors and other localized sites of disease. Though the body's own cells are protected from the immune system by their protein-studded outer membrane, it's not possible to re-create this complex matrix for synthetic particles used in drug delivery.

SOLUTION: Why not cloak therapeutics in natural membranes? That's the idea of Liangfang Zhang, a nanoengineering professor at UC San Diego.

Zhang derives red-blood-cell membranes from blood samples and uses them to coat polymer nanoparticles. Because these particles look like red blood cells on the surface, they can fool the immune system; loaded with drugs, they serve as robust and long-lived drug carriers. An unexpected bonus: they can also act like nanoscale sponges to suck up toxic proteins produced by infectious bacteria or introduced by snake or insect venom. If the particles flood the bloodstream, they will divert most of the toxin away from actual cells.

Born in Wuwei County, 45 minutes by plane from Shanghai, Zhang left home for the prestigious Tsinghua University in Beijing when he was just 15. By the time he was 20 years old, he could have opened a factory to produce exceptionally tough rubber materials he'd helped invent as a student. But Zhang says he "didn't want to run a rubber factory all my life." And he knew if he started a factory, some other young upstart would come up with a better technology and he might not be able to compete. So he decided to pursue an advanced graduate degree in engineering in the United States. Despite his accomplishments as a scientist, however, he has never lost his desire to turn laboratory advances into practical breakthroughs. —*Katherine Bourzac*

LESLIE DEWAN, 28

What if we could build a nuclear reactor that costs half as much, consumes nuclear waste, and will never melt down?

The nuclear power industry has a reputation for resisting innovative changes. But Leslie Dewan and a colleague have dared to invent a new type of nuclear reactor. "We were feeling on top of the world. We just passed our qualifying exams for our PhDs. We thought, 'We're

COURTESY OF LESLIE DEWAN

Portrait by Brett Affrunti

the smartest we've been in our lives. We can do anything. Let's change the world with nuclear.'" Two years later, she'd designed a reactor that solves the main problems facing nuclear power. To commercialize it, she'd cofounded a startup, Transatomic Power.

For decades the nuclear industry has built one type of reactor, called a light-water reactor, almost exclusively. There are significant problems with that technology, which uses ordinary water to cool the fuel rods in which the nuclear reaction takes place. It requires expensive safeguards against a radiation-releasing meltdown if the fuel rods overheat; it produces waste products that are dangerous for 100,000 years. Dewan and a fellow graduate student, Mark Massie, designed an alternative based on molten-salt reactors that were originally proposed in the 1950s as a way to power aircraft. Though nuclear planes never became a reality, the reactor design has several key advantages. For one thing, it can be readily modified so that rather than producing large amounts of waste, it reuses much of the spent nuclear material as fuel.

It is also far safer than the light-water reactors, which require a constant source of electricity to pump in cool water and prevent the runaway nuclear reactions that lead to meltdowns. Molten salt serves as the coolant; it's mixed with the nuclear materials, so the reactions take place right in the liquid. The heat of those reactions keeps the salt molten. A plug at the bottom of the reaction vessel is made of the same salt, kept solid by cooling it; if the plant's electricity supply is lost, the plug warms up and liquefies, allowing the contents of the reactor to drain into a large containment tub and spread out so that the nuclear chain reactions come to an almost complete stop. The nuclear material and molten salt then cool down and turn into a contained solid that poses no danger of a meltdown.

The technology had one glaring problem, though: the reactors were large and, thus, expensive for the amount of power they produced. Dewan found a solution. "We realized that with some relatively modest changes to molten-salt reactors we could make them much more power dense and therefore a lot cheaper," she says. She introduced new materials and a new shape that allowed her to increase power output by 30 times. As a result, the reactor is now so compact that a version large enough for a power plant can be built in a factory and shipped by rail to a plant site, which is potentially cheaper than the current practice of building nuclear reactors on site.

The reactor also makes more efficient use of the energy in nuclear fuel. It can consume about one ton of nuclear waste a year, leaving just four kilograms behind. Dewan's name for the technology: the Waste-Annihilating Molten-Salt Reactor.

So far, the design exists as a 180-page document, computer simulations, and patent filings. Dewan has designed five experiments, each of which will cost about $1 million, to prove key aspects of the design. If those go well, she'll still face a decade or more of further tests and U.S. federal certifications that could cost hundreds of millions of dollars. And she suggests that the future for new nuclear-power technology might not be in the United States. She points in particular to China, which is spending far more on new reactor designs and on the construction of nuclear plants.

437
Number of nuclear reactors operating around the world

But though it will be a long and uncertain route to commercialization of the technology, Dewan is driven by what is at stake. She's part of a new generation of young researchers who see nuclear energy as one of the best hopes for averting disastrous climate change. Dewan originally looked to solar and wind power as ways to reduce carbon dioxide emissions, but "then I looked at the numbers," she says. "I realized that nuclear power is the best low-carbon energy source that's available and scalable." *—Kevin Bullis*

DATA FROM EUROPEAN NUCLEAR SOCIETY

Illustration by Golden Cosmos

What do your genes say about how smart you are?

BOWEN ZHAO, 21

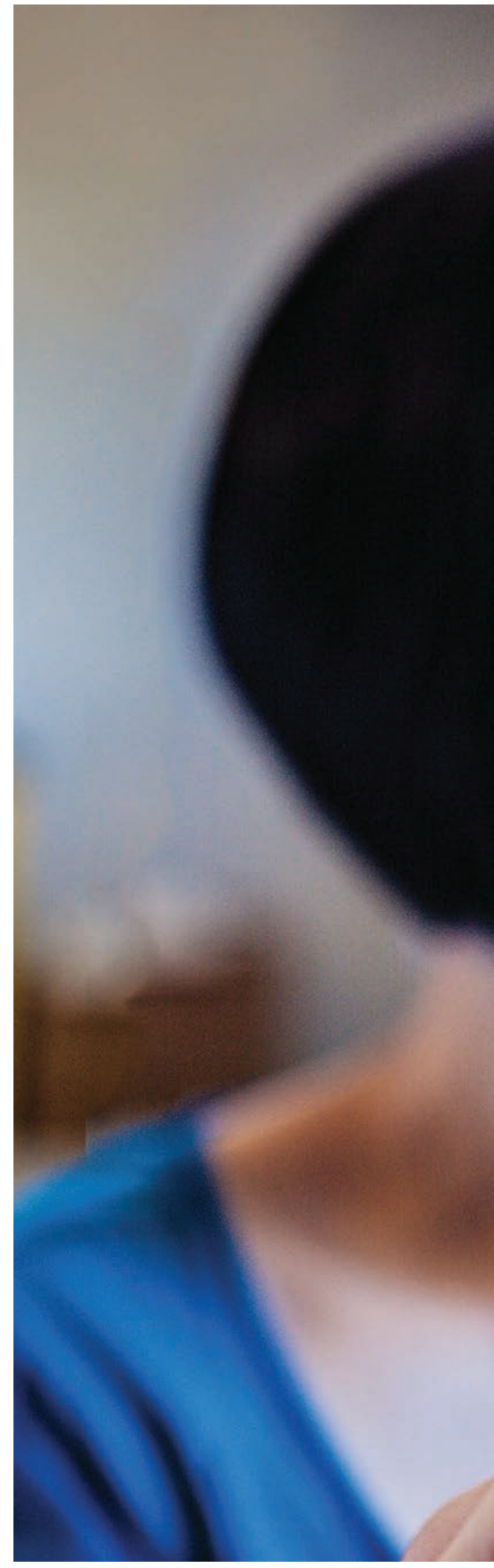
Bowen Zhao dropped out of Beijing's top high school to take a job at BGI-Shenzhen, the world's largest DNA-sequencing organization. Soon after joining the company, he became involved in a new research effort: investigating the genetic basis of human cognitive abilities, including intelligence. "We want to know the genetic basis of IQ," he says. Zhao thinks human intelligence is from 40 to 80 percent inheritable, and he wants to know which genes may influence the trait he calls "high cognitive ability."

Zhao's team is sequencing the DNA of more than 2,000 people with high IQs. Zhao is not looking for an IQ gene; rather, he expects to pinpoint multiple small variations in thousands of genes that shape the inheritable aspect of intelligence. Perhaps uniquely in the world, BGI has both the massive computing power and the manpower to handle a data-intensive approach to combing through the genetic clues. "We're data driven, not hypothesis driven," says Zhao.

The project involves sequencing more than six trillion DNA bases. This is not the first attempt to map the biological roots of human intelligence. But now, Zhao points out, DNA sequencing technology is so advanced that it's possible to sequence and compare thousands of minute variations in extremely large samples.

Zhao is keenly aware that research into the genetic basis of intelligence is controversial and fraught with ethical dangers. But he says that for the foreseeable future, if you want to measure someone's intelligence, it will be far easier and more accurate to conduct a standard IQ test than to give a genetic-based one.

—Christina Larson



Portrait by Brett Affrunti

XIAOLIN ZHENG, 34

An ingenious solar sticker made with techniques drawn from nanotechnology could turn almost any surface into a source of power.

Stanford professor Xiaolin Zheng often works in the esoteric fringes of nanoscience, but she also likes to find simple ways to fabricate complex materials that can be put to use in practical applications like solar-fuel systems, solar cells, and batteries. Last year she created solar cells in the form of flexible stickers—only a 10th as thick as plastic wrap—that can be applied to a window, a piece of paper, the back of a mobile phone, or anything else you want. These solar cells produce just as much electricity as rigid ones made of the same materials.

Zheng got the inspiration for this invention from her father. One day when they were talking on the phone—he in China, she in California—he said that it should be possible to put solar cells on the walls of buildings, not just the roof. And Zheng's daughter, like many kids, loves stickers.

All this was in the back of Zheng's mind when she read a research paper about graphene, a novel type of nanomaterial. The researchers grew the material on a layer of nickel on top of a silicon wafer. When they put the whole thing in water, the nickel separated from the surface, taking the graphene with it. "I couldn't believe that soaking in water would do this," she says.

Zheng has demonstrated this water-soaking approach as a way to peel off thin-film silicon solar cells grown on a rigid substrate. It turns out the phenomenon—called water-assisted subcritical debonding—had been known since the 1960s, but no one before had tried using it to make flexible electronics. She hopes the technology will be scaled up beyond the one-square-centimeter devices she's made so far, so that the sides of buildings can one day be papered with solar cells as her father suggested. *—Katherine Bourzac*

Photograph by Timothy Archibald

A BUSINESS REPORT ON

The Next Silicon Valley

Every region dreams of becoming the cradle of tomorrow's technology. Here's how history, luck, and sheer population size shape competitive advantage.

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JASPER RIETMAN

The Big Question

In Innovation Quest, Regions Seek Critical Mass

What's the secret to becoming the next technology hot spot?

● There is a place in Cambridge, Massachusetts, just off the MIT campus in Kendall Square, that is home to the densest concentration of startups anywhere in the world. There, founders of 450 companies crowd into nine floors, many in common rooms where the rule is "Grab any seat you can."

On a heat map of innovation, the place is glowing red. Sharing the same elevator banks are venture capital firms that collectively manage $8.7 billion. Fifteen years ago, the local tech scene was anemic and there were few investors. Now Kendall is a beacon that's drawing more and more technology companies. Amazon moved its mobile development team to the area, Google is expanding, and drug companies are piling in, too. →

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Kendall has become what economists call a cluster, a concentration of interconnected companies that both compete and collaborate. There's economic value in that, as the price of office space attests: rents have spiked to $70 per square foot from $35 a decade ago, similar to what you'd pay in midtown Manhattan. "Rents don't lie," says Tim Rowe, head of the Cambridge Innovation Center, the shared office space where most of the startups are located.

There's value to the region as well. Cities used to try to win jobs by "smokestack chasing," or luring big industries. But large existing firms tend to shed jobs. At least in the United States, nearly all job growth comes from startups, especially the kind that explode from a few employees to several thousand. In technology, those winners have a way of producing more winners. The process reaches critical mass in the web of intertwined companies, resources, advantages, ideas, talent, opportunity, and serendipity that defines a technology cluster.

It's clear that what's essential is proximity to human talent. Jean-François Formela, a venture capitalist at Atlas Venture who invests in early-stage biotechnology startups, says he visits Boston-area academic labs several times a week, trying to find the next invention that he can license and turn into a company. And because there are so many PhDs and MDs in the area, he can start a company and build a team remarkably fast. "People don't even have to change buildings," he says. "They just switch floors."

The big questions in this *MIT Technology Review* Business Report are why technology clusters arise and what ingredients can create one. Unhappily for regions that have spent billions to become the next Silicon Valley, the answers are still in debate. "Clusters exist—it's empirically proven," says Yasuyuki Motoyama, a senior scholar at the Kauffman Foundation. "But that doesn't mean governments can create one."

$2.5 billion
Planned Russian investment in the Skolkovo innovation city

What's certain is that they are trying. The largest such effort we know of is the Skolkovo complex now rising outside Moscow, where $2.5 billion is being invested in a university, a technology park, and a foundation. Another, in Waterloo, Ontario, aims at gaining a lead in a particular advanced technology, quantum computing. The price tag there: more than $750 million.

The problem for governments is that they often try to define where and when innovation will occur. Some attempt to pick and fund winning companies. Such efforts have rarely worked well, says Josh Lerner, a professor at Harvard Business School. Governments can play a role, he says, but they should limit themselves mostly to "setting the table": create laws that don't penalize failed entrepreneurs, lower taxes, and spend heavily on R&D. Then get out of the way.

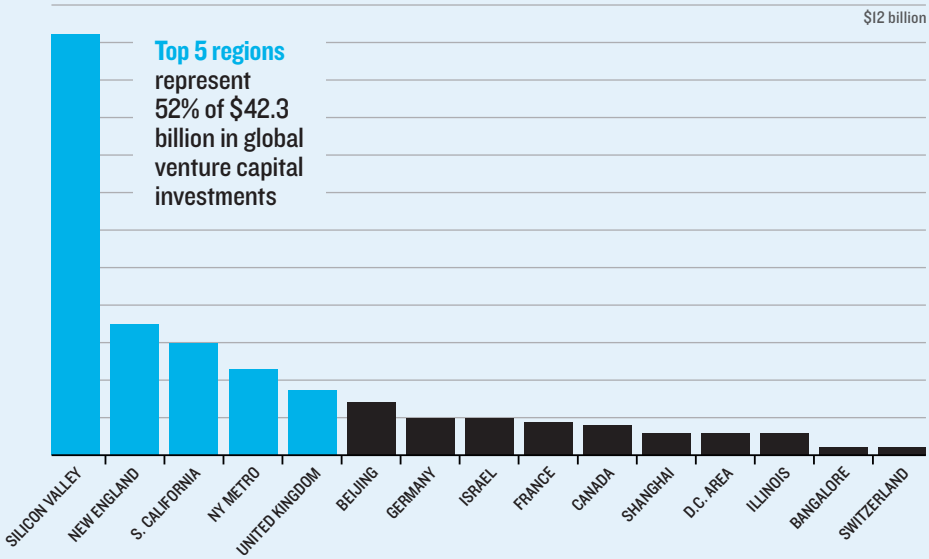
Despite the difficulties, ever more cities now aspire to become technology hubs. One reason is that the Internet has spread both the ideology of startup culture (you, too, can be Mark Zuckerberg) and the means of participating through apps and Web software. Every place from Chile to Iceland seems to have created a startup accelerator in an effort to jump-start its own tech scene without expensive laboratories or even a top university.

One proponent of this idea is Brad Feld, a partner at Foundry Group, creator of the technology incubator Techstars, who developed what he calls the "Boulder Thesis" based on his experiences in Colorado. It is a four-point plan for how entrepreneurs—not governments or universities—can organize and create "entrepreneurial communities" in any city. Feld says the startup movement is now an "enormous global community with ... hundreds of thousands of people around the world."

But can entrepreneurs succeed in creating clusters where governments have had so much difficulty? "The conflict now is between two logics on how to create an ecosystem," says Fiona Murray, a professor at MIT's Sloan School, who consults as a kind of therapist to clusters, including London's Tech City. One is "a government logic that says it's too important to leave to entrepreneurs, and that you that need specialized inputs, like a technology park." The other is "purely focused on people and their networks."

There is one finding economists tend to agree on. Centers of innovation do move, sometimes rapidly, and they tend to go where the latest mousetrap was invented. Boston gave up its lead in computing to Silicon Valley in the 1980s, after the personal computer was developed. But who knows? One of those 450 startups in Kendall might just hit upon something big. That's a reason any place can still hope—with a few decades of effort, and plenty of luck—to become a Silicon Valley too. *—Antonio Regalado*

Winner Take All
Venture capital investments in top hot spots, 2012



SOURCE: ERNST & YOUNG

Case Studies

Silicon Valley Can't Be Copied

For 50 years, the experts have tried to figure out what makes Silicon Valley tick. The answer is people.

● By 1960, Silicon Valley had already captured the attention of the world as a teeming technology center. It had spawned the microwave electronics industry and set a pattern for industry-academic partnerships. French president Charles de Gaulle paid a visit and marveled at its sprawling research parks set amid farms and orchards south of San Francisco.

Stanford University, which is at the heart of Silicon Valley, had given birth to leading companies such as Hewlett-Packard, Varian Associates, and Applied Technologies. These companies were pushing the frontiers of technology. There was clearly something unusual happening here—in innovation and entrepreneurship.

Soon enough, other regions were trying to copy the magic. The first serious attempt to re-create Silicon Valley was conceived by a consortium of high-tech companies in New Jersey in the mid-1960s. They recruited Frederick Terman, who was retiring from Stanford after having served as provost, professor, and engineering dean.

Terman, sometimes called the "father of Silicon Valley," had turned Stanford's fledgling engineering school into an innovation engine. By encouraging science and engineering departments to work together, linking them to local firms, and focusing research on the needs of industry, he created a culture of coöperation and information exchange that still defines the region.

That was the mixture New Jersey wanted to replicate. It was already a leading high-tech center—home to the laboratories of 725 companies, including RCA, Merck, and the inventor of the transistor, Bell Labs. Its science and engineering workforce numbered 50,000. But because there was no prestigious engineering university in the area, its companies had to recruit from outside, and they feared losing their talent and their best technologies to other regions. (Even though Princeton was nearby, its faculty generally shunned applied research and anything that smelled of industry.)

New Jersey's business and government leaders, led by Bell Labs, decided that the solution was to build a university much like Stanford. And that is what they hoped Terman would do.

Terman drafted a plan, but he could not get it off the ground, largely because industry would not collaborate. This history was documented by Stuart W. Leslie and Robert H. Kargon in a 1996 paper, "Selling Silicon Valley." They report that RCA would not sign up for a partnership with Bell Labs, and that Merck and other drug firms wanted to keep their research dollars in house. Despite common needs, companies would not work with competitors.

Terman would later try again in Dallas. But he failed for similar reasons.

In 1990, Harvard Business School professor Michael Porter proposed a new method of creating regional innovation centers—this time around an existing research university. He observed that geographic concentrations of interconnected companies and specialized suppliers gave certain industries productivity and cost advantages. Porter postulated that by bringing these ingredients together into a cluster, regions could artificially ferment innovation.

Porter and legions of consultants following his methodology prescribed top-down clusters to governments all over the world. The formula: select a hot industry, build a science park next to a research university, provide subsidies and incentives for chosen industries to locate there, and create a pool of venture capital.

Sadly, the magic never happened—anywhere. Hundreds of regions worldwide collectively spent tens of billions of dollars trying to build their versions of Silicon Valley. I don't know of a single success.

What Porter and Terman failed to recognize is that it wasn't academia, industry, or even the U.S. government's funding for military research in aerospace and electronics that had created Silicon Valley: it was the people and the relationships that Terman had so carefully fostered among Stanford faculty and industry leaders.

AnnaLee Saxenian, a University of California, Berkeley, professor, understood the importance of people, culture, and connections. Her 1994 book *Regional Advantage: Culture and Competition in Silicon Valley* compared the evolution of Silicon Valley with that of Route 128—the ring around Boston—to explain why no region has been able to replicate the California success.

Saxenian noted that until the 1970s, Boston was far ahead of Silicon Valley in startup activity and venture capital investments. It had a huge advantage because of its proximity to East Coast industrial centers. By the 1980s, Silicon Valley and Route 128 looked alike: a mix of large and small tech firms, world-class universities, venture capitalists, and military funding. And then Silicon Valley raced ahead and left Route 128 in the dust.

52%

Proportion of Silicon Valley firms with at least one foreign-born founder

The reasons were, at their root, cultural. It was Silicon Valley's high rates of job-hopping and company formation, its professional networks and easy information exchange, that lent the advantage. Valley firms understood that collaborating and competing at the same time led to success—an idea even reflected in California's unusual rule barring noncompete agreements. The ecosystem supported experimenting, taking risks, and sharing the lessons of success and failure. In other words, Silicon Valley was an open system—a giant, real-world social network that existed long before Facebook.

It also doesn't hurt that Silicon Valley has excellent weather, is close to mountains and the ocean, and has a myriad of state-park hiking trails. These help foster a culture of optimism and openness. →

From 1995 to 2005, 52 percent of Silicon Valley startups had one or more people born outside the U.S. as founders, twice the rate in the U.S. as a whole. Immigrants like me were able to learn the rules of engagement, create our own networks, and participate as equals. These days, the campuses of companies such as Google resemble the United Nations. Their cafeterias don't serve hot dogs; they serve Chinese dishes, and curries from both northern and southern India.

This is the diversity—a kind of freedom, really—in which innovation thrives. The understanding of global markets that immigrants bring with them and the links to their home countries have given the Valley an unassailable advantage as it's evolved from radios and computer chips to search engines, social media, medical devices, and energy technology.

The Valley is a meritocracy that's far from perfect, however. Some of its flaws tear at the very fabric that makes it unique. Women and minorities are largely absent from the ranks of company founders and boards. Venture capitalists tend to fund startups that produce short-term results—leading to a preponderance of social-media and photo-sharing apps. Real-estate prices are so high that most Americans can't afford to relocate there.

All these things slow the Valley down, but they won't stop it. The only serious challenge I see to Silicon Valley is, ironically, from the same government that once catalyzed its development. Silicon Valley is starved for talent. Restrictions on work visas prevent foreigners from filling its openings. There are more than one million foreign workers on temporary work permits now waiting to become permanent residents. The visa shortage means some will have to leave, and others are getting frustrated and returning home.

This brain drain could bleed the life out of Silicon Valley's companies. Then we will have real competitors emerging in places like New Delhi and Shanghai. But it won't be because they discovered some recipe for innovation clusters that finally works. It will be because we exported the magic ingredient: smart people.

—Vivek Wadhwa

Leaders

Beijing's Great Leap Forward

Kai-Fu Lee trained an army of Chinese engineers. Now they're turning Beijing into a technology powerhouse.

● Cities all over the world have tried to duplicate Silicon Valley. But only one has emerged as a serious contender: Beijing.

China's political, financial, and cultural capital has been on a startup tear in recent years. In 2011, Chinese venture capital firms invested $13 billion, half as much as their U.S. counterparts—30 percent of it in Beijing. (The total investment dipped sharply in 2012 in the face of a national economic slowdown.) Beijing hosts rare concentrations of wealth and some 70 institutions of higher learning, including China's best computer science departments. Like New York, it's a magnet for ambitious young people. Like Washington, D.C., it's the center of the national government. Beijing produces what few other places can—giant, fast-growing tech companies, like Baidu (now worth $31 billion), Lenovo, and smartphone maker Xiaomi, which sold $2 billion in handsets last year.

"The pace is faster here. Companies iterate, build things, and grow faster than their U.S. counterparts."
—Kai-Fu Lee

Among the city's 20 million residents, probably none can take more credit for Beijing's trajectory from backwater to startup factory than Kai-Fu Lee. As the founder of Microsoft Research Asia and Google China, the U.S.-educated computer scientist not only became one of China's first tech celebrities but personally trained a generation of engineers whose business ventures have turned Beijing into a dynamic technology center. More recently, Lee founded Innovation Works, a Beijing-based incubator and venture capital firm dedicated to nurturing Chinese startups.

Beijing now is not just competent in software and gadgets. It has its own brands that are bound to lead in their own directions. "I've seen startup clusters all over the world," says Steve Blank, an entrepreneur and business school professor who recently returned from a visit to China. "But Beijing blew me away. They've built an ecosystem on a scale that puts Boston or Seattle to shame. Beijing compressed 30 years of startup learning into five years."

Lee, who is 51, was born in Taiwan and moved with his family to the U.S. in 1973. As a PhD candidate at Carnegie Mellon, in Pittsburgh, he was struck by the technological gap between the U.S. and China. While he wrote and debugged his code at a computer, a classmate from the People's Republic executed those tasks on paper. "That opened my eyes about the backwardness of Chinese computing in general, not to mention innovation," he says.

At that time, China's government had set in motion ambitious plans to break into high-tech and electronics manufacturing. In the 1980s it opened the Zhongguancun technology hub in Beijing (now home to Lenovo), the first of 54 similar science and innovation parks that took Silicon Valley as their inspiration.

Lee's chance to play a role came in 1997, after Bill Gates visited China and decided to gain a stronger Asian foothold for Microsoft's products. The following year, Gates sent Lee to Beijing to launch what became Microsoft Research Asia.

Already a veteran of Silicon Graphics and Apple, Lee quickly realized that given the lack of experienced managers and the authoritarian bent of Chinese society, he

needed to organize teams of "soldiers" directed by a "general" rather than follow the every-man-for-himself approach typical of U.S. labs. "I had one general leading 10 soldiers, and the soldiers were so grateful and dedicated, they'd work nights and weekends," he recalls.

Under Lee, Microsoft's platoons learned how to focus on an engineering problem and produce a creative solution, China-style. And by the time Google recruited him in 2005 to establish Google China, government programs to promote technology education were bearing fruit. "I saw a dramatic improvement from programming on paper to dozens of hirable engineers to thousands," he says.

Many of Lee's generals, trained in producing software for big companies, took their experience to up-and-coming Beijing firms such as e-commerce specialist LightInTheBox and smartphone maker Xiaomi, whose cofounder Lin Bin had followed Lee from Microsoft to Google. These firms had a clear view of the Chinese market and could navigate policies that have made it difficult for some U.S. firms to do business (Google moved its search engine to Hong Kong in 2010).

Meanwhile, Chinese society has begun another shift. Before Microsoft and Google arrived, being a startup founder was not a socially acceptable career path. Parents pushed young people to find a job with an established company (and to a large extent still do). But these days, there's also a popular reality TV show on which entrepreneurs pitch angel investors for seed funding. "I can't overstate the importance of that," says William Bao Bean, managing director at SingTel Innov8, a venture capital firm. "The entrepreneurs are driven, they want to start up. But the people around them needed that education."

China's Internet successes have been viewed as clones of foreign products. Tencent openly copied the ICQ chat client. Baidu imitated Google. Yet each triumphed in what is now the world's largest Internet market, with some 560 million users. By Kai-Fu Lee's count, for instance, Groupon spawned 6,500 Chinese imitators, of which only a few survive. "Where else can you try something like that?" asks David Lin, Microsoft Ventures' director for greater China. "The market scale can afford this kind of rapid experimentation, and the best prevail."

The urge to replicate existing products is also receding as Chinese startups learn how to home in on customer needs and, in many cases, adopt what are known in Silicon Valley as "lean startup" principles. In Lee's view, these tenets—proactive market research, minimal features, rigorous measurement, rapid iteration—are perfectly suited to the Chinese character. "The lean-startup model," he says, "takes full advantage of the traits of Chinese people: hardworking, dedicated, focused, led by one person with a strong direction."

560 million
The number of Internet users in China

At Innovation Works, his current venture, Lee is using those principles to provide what is, in China, a rare degree of support for experimentation and failure. And he's aiming specifically to nurture entrepreneurs who haven't set foot outside China. The $500 million investment fund has among its higher-profile investments the "light blogging" platform DianDian and the photo-sharing network PaPa. Both companies were started by Xu "Jack" Chaojun, a mainland entrepreneur who's never worked or studied overseas.

Xu represents a new generation for whom experience abroad is proving less important than direct experience serving Chinese customers. "A mainland engineer who spends too much time in the U.S. can lose touch with how Chinese users behave," says Hans Tung, managing partner at Qiming Venture Partners. "The skill set is transferable, but we're dealing with dramatically different user behavior."

The innovations coming out of Beijing are still limited in scope. They don't threaten Silicon Valley's monopoly on products so fresh and powerful that few customers would think to ask for them—items like the personal computer and Google Glass. Lee doubts Chinese entrepreneurs are likely to produce things like that anytime soon. For one thing, they have their hands full serving the Chinese Internet market. Moreover, it will be some time before they're consistently able to crack markets where Chinese isn't the dominant language. "It's not just China," he notes. "It's not clear that any country other than the U.S. can come out with so many disruptive innovations at scale."

But things change quickly in Beijing. So quickly, in fact, that Lee thinks his adopted city might eventually challenge California as an innovation leader. "The pace is faster here," he says. "Companies iterate, build things, and grow faster than their U.S. counterparts. So it's possible that new ideas will arise in China and be ready for the world before any U.S. company is even doing that thing. It's an exciting opportunity." —*Ted Greenwald*

SOURCES: BEIJING STATISTICS BUREAU, DOW JONES VENTURESOURCE, CNNIC, *2012

World Innovation Clusters

Innovation clusters are places with dense webs of interconnected technology companies, customers, and suppliers. Improving a cluster's chance of flourishing are factors such as liberal immigration laws and venture capital financing, research has shown. In the map below, we rate five of the largest regional technology clusters as well as three newer, government-supported efforts to fuel innovation in Russia, France, and the United Kingdom.

KEY

- **STRONG IP PROTECTION**
- **GOOD WEATHER**
- **LIBERAL IMMIGRATION LAWS**
- **ENTREPRENEURIAL CULTURE**
- **FLAG = GOVERNMENT CLUSTER**

SILICON VALLEY

Venture capital: $11.2 billion*

Top companies: Google, Apple

Key facts:
- 64% foreign workers
- 17 IPOs in 2012

BOSTON

Venture capital: $3.6 billion

Top companies: Akamai, Genzyme

Key facts:
- Most U.S. biomedical funding
- 85 colleges and universities

TECH CITY LONDON

Venture capital: $161 million

Top companies: Techstars, Last.fm

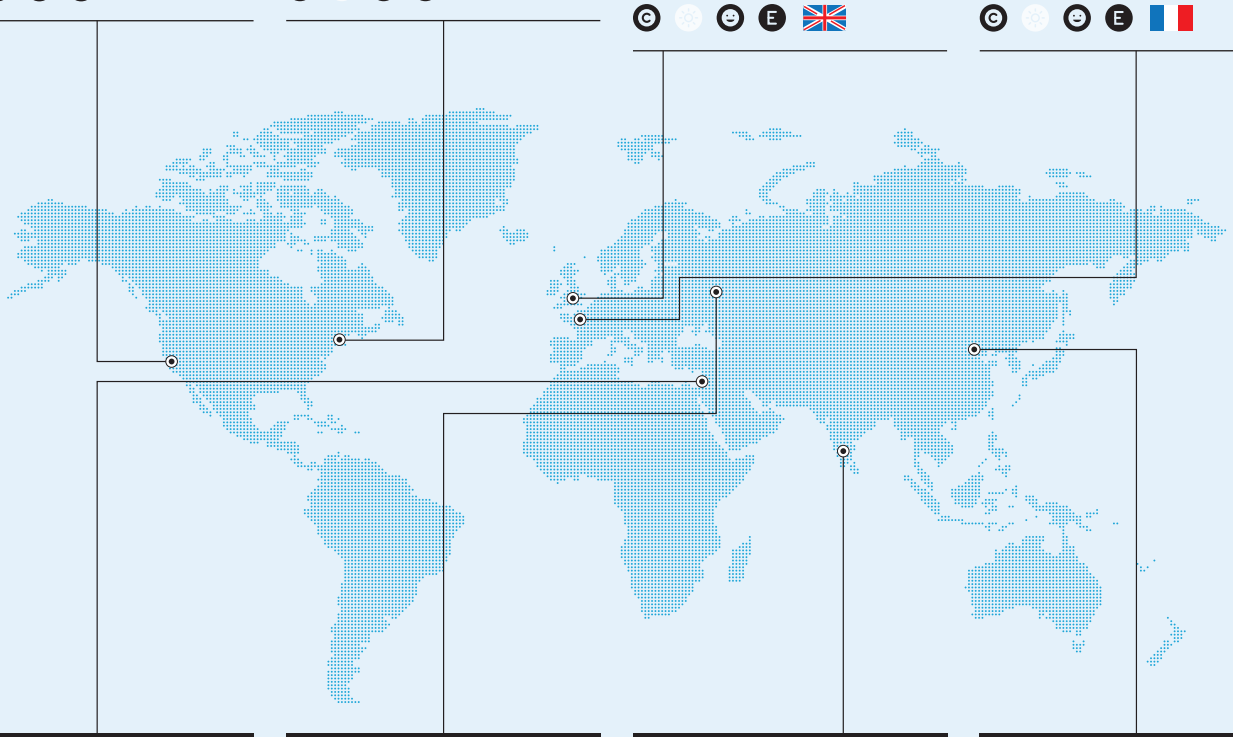
Key facts:
- Startup initiative created in 2010
- 140 technology companies
- Tax breaks for private investors

PARIS-SACLAY

Government funding: $3.25 billion

Top companies: EADS, Siemens

Key facts:
- Construction began in 2013
- Two-square-kilometer campus
- Merging six engineering schools



ISRAEL

Venture capital: $1 billion

Top companies: Waze, Teva

Key facts:
- 230,000 high-tech workers
- Compulsory military training
- $25 billion in technology exports

SKOLKOVO INNOVATION CITY

Government funding: $2.5 billion

Top companies: IBM, Rusnano

Key facts:
- Founded in 2010
- 900-acre innovation center
- University designed by MIT

BANGALORE

Venture capital: $300 million

Top companies: Infosys, Wipro

Key facts:
- Internet users up 26% per year
- $3,876 per capita income (India)
- Over 10,000 local millionaires

BEIJING

Venture capital: $1.4 billion

Top companies: Baidu, Lenovo

Key facts:
- 70 colleges and universities
- 30% of China's venture funding
- 14.5 million Internet users

SOURCES: ERNST & YOUNG, BLS, SKOLKOVO FOUNDATION, PARIS-SACLAY DEVELOPMENT AUTHORITY, MASSBIO, KPCB, WORLD BANK, THE GUARDIAN, TECH CITY INVESTMENT ORGANIZATION, UKFUNDERS, SILICON VALLEY INDEX, TAYLOR WESSING, IMPERIAL COLLEGE, UNITED NATIONS. *VENTURE CAPITAL FIGURES ARE FOR 2012. SILICON VALLEY INCLUDES THE BAY AREA, AND BOSTON FIGURES INCLUDE THE GREATER METROPOLITAN REGION.

Emerged Technologies

Israel's Military-Entrepreneurial Complex Owns Big Data

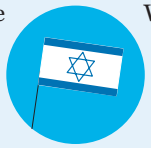
Technology to track enemies powers Israel's move into commercial prediction software.

● Two years ago, a half-dozen programmers started working together in a Tel Aviv basement to create one of Israel's 5,000 high-tech companies. It was a stealth company, but these 20-somethings were used to secrecy. Most had served together in a military intelligence unit of the Israel Defense Forces.

In the army, they worked on algorithms that could predict the behavior of Israel's enemies by plucking patterns from intercepted signals. Their new company, Any.Do, was based on much the same idea—but aimed instead to guess the preferences of consumers. By this year, Any.Do's productivity app for smartphones was one of the most popular downloads worldwide.

Each year, Israel's military puts thousands of teenagers through technical courses, melds them into ready-made teams, and then graduates them into a country that attracts more venture capital investment per person than anywhere else in the world and exports $25 billion a year in high-tech goods and services. The result, according to the 2009 book *Start-Up Nation*, is an "economic miracle."

Israel's military-entrepreneurial complex has lent it a particular edge in analytics and big data. "Their main expertise was to extract intent from messages that are being sent across different communications channels," says Any.Do CEO Omer Perchik of his team. What they're building, he says, is a "kind of action engine" that can "extract the user's intent" from a list of tasks and appointments.



Military service in Israel is generally compulsory, lasting two or more years. Many would-be entrepreneurs apply to the IDF's computer training academy, known as Mamram. Located at a base outside Tel Aviv, it acts a bit like a school for startups, teaching programming and project management to cadets in olive-green uniforms. Young hackers with proven skills get recruited by specialized intelligence units such as Matzov, the army's cybersecurity division, or units involved in signals intelligence and eavesdropping.

"What happens in the military is we take these really bright young 18-year-olds and say: Here's a data center the size of Google and Facebook combined. Go do something mission critical," says Michael Eisenberg, a general partner at the venture capital firm Benchmark Capital. "Now they are spilling out of the army, and we have the highest and best concentration in Israel of big-data engineers and analysts anywhere in the world."

That explains why IBM, Google, Microsoft, EMC, Intel, eBay, Cisco, and other giants all have major research centers in Israel, where more than 230,000 people are employed in high-tech fields. In the past two years, Israeli companies specializing in mobile computing, cybersecurity, and data storage have been snapped up for ever-increasing sums, culminating in Google's acquisition of the mapping app Waze for more than $1 billion in June.

Israelis' shared cultural identity also plays a role in the country's startup success. Eric Schmidt, chairman of Google, said after visiting Tel Aviv last summer that Israeli entrepreneurs possessed a distinctive "live for today" attitude toward taking risks.

Sometimes the military connection to startups is obvious: the pill-sized diagnostic camera developed by Given Imaging is based on the equipment in the nose of a military drone. Other connections are more obscure. Some aspects of Israeli expertise in mobile communication networks, for example, were developed as part of a defensive measure against terror attacks by Palestinians. The details are still top secret.

Another factor boosting Israel's startup scene is the low cost of college, about $3,000 a year. Students typically emerge from military service and university with no debt, which allows many to take a year off to pursue their dreams.

Sometimes those dreams come true. The success of Waze has roiled an already bubbling market. Just as Any.Do is based on predictive analysis of large amounts of data, Waze applies the same techniques to crowdsource accurate traffic information and maps in real time. Waze's cofounder Uri Levine also got his start as a military software developer.

"Big data was not a brand 10 years ago, but it was already there in intelligence organizations," says Elik Ber, a former army officer with Meidata, a research company. "Now when a consumer company wants to know who bought their product everywhere in the world, they're facing the same kind of challenge."

—Matthew Kalman

Startup Nation

How much was paid for Israeli startups in 2013

NAME	Waze	Intucell	ScaleIO	dbMotion
PRODUCT	Crowdsourced maps app	Mobile network software	Data center storage	Electronic medical records
ACQUIRED BY	Google	Cisco	EMC	Allscripts
PRICE	$1 billion	$475 million	$250 million	$235 million

SOURCE: COMPANY REPORTS

Emerged Technologies

The Bell Labs of Quantum Computing

Mike Lazaridis invented the BlackBerry. Now he wants to create an industry around quantum computing.

● Raymond Laflamme can't yet sell you a quantum computer. But he'll sell you a $13,000 logic board for measuring entangled photons.

It's a start.

Laflamme is head of the Institute for Quantum Computing at the University of Waterloo, a research center that's part of a quixotic, grandiose effort by Mike Lazaridis, cofounder of the smartphone maker BlackBerry, to invent a quantum computer and turn this city 70 miles from Toronto into a "Quantum Valley."

Since 1999, Lazaridis has put $270 million into his vision, paying to recruit some of the world's best theoretical physicists. While he thinks a true quantum computer is still 10 years away, he believes initial discoveries can be commercialized now, turning Waterloo into a thriving industrial cluster built around quantum information science.

The University of Waterloo has one of world's best computer science departments. The city is also corporate home to BlackBerry and an increasingly rich ecosystem of startups. But quantum mechanics is not exactly an easy elevator pitch. "As much as the region is a mecca for entrepreneurship, it's a much different challenge to commercialize pure quantum technology," says Rolf Horn, a postdoc at the institute, who's trying to start a company to sell a device that can produce photons that exhibit quantum effects.

Quantum computers should have the ability to quickly solve problems that today's computers cannot touch, such as breaking very difficult cryptographic ciphers. What's more, fast progress in conventional computing—described by Moore's Law—is nearing the physical limits of materials like silicon. You "don't have to know a lot about physics" to realize there's money to be made pushing past those limits, Lazaridis says.

It is still very early days for quantum computers. At the Institute for Quantum Computing, also funded heavily by Canada's government, the most complex quantum computer operates with just 12 qubits. A qubit is the quantum equivalent of a bit. Thanks to quantum mechanics, each qubit can be in multiple states simultaneously (imagine a bit that could be a *0*, a *1*, or both at once). That permits faster calculations for some problems, but keeping qubits stable has proved difficult.

Lazaridis has used his wealth to bring top scientists to Waterloo, starting with a $100 million gift in 2000 to create the Perimeter Institute for Theoretical Physics. But the effort may not be able to rely on his largesse forever. His wealth, at least on paper, has plummeted by more than $2 billion along with BlackBerry's stock price as its phones have lost popularity. In a 2012 shakeup, Lazaridis stepped down as BlackBerry's co-CEO.

Quantum computers could quickly solve problems that today's computers cannot touch, like breaking difficult cryptographic ciphers.

Quantum Valley also won't become a real industry cluster if all it does is recruit the world's best academic researchers. That is one reason why in March, Lazaridis and Doug Fregin, BlackBerry's other founder, launched a $100 million investment fund, Quantum Valley Investments. "We built all this and it was very altruistic, very much philanthropy," says Lazaridis. "But some of the researchers came to us and said, you know, this quantum computer—some of the technology we're working on has spinoffs."

Laflamme has gadgets reflecting a few of those ideas spread out on a coffee table in his office, including a simple two-qubit processor with the solder still visible, and a metal box the size of a router that's useful for measuring photon sources. That box is the basis of his small startup company, Universal Quantum Devices.

Laflamme calls the company an "experiment" in how to commercialize basic aspects of quantum technology. If it seems like small stuff, recall that the first products of Hewlett-Packard, Silicon Valley's original computing giant, were frequency counters and a simple oscillator for measuring sound.

Other commercialization efforts include a satellite that could use quantum properties of light to send encrypted communications. A prototype was tested this summer by putting it on a flatbed truck and running it around Waterloo's wheat fields, to see if it tracked with an optics receiver on the roof of the institute's research buildings.

Lazaridis's new venture fund has not yet invested in any of these ideas. Still, Laflamme says things are going better than he expected. "In 2001, people would say, 'When are you going to have spinoffs coming out?' and I would say 20 years, thinking, 'I'll be safe with that,'" he says. "Now I can see it coming." —*Michael Fitzgerald*

Quantum Effects, Big Costs

Costs to build a quantum computing cluster in Waterloo, Canada (in millions)

Mike Lazaridis	$270
Canada	$215
Ontario	$161
University of Waterloo	$100
Foundations	$9
BMO Financial	$4
Total commitments	**$759 million**

UNIVERSITY OF WATERLOO, MIKE LAZARIDIS

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New Forms That Function Better

Design software helps architects create museums, arenas, and other grand projects with fanciful, otherworldly forms. It's time to put the technology to better use: optimizing everyday buildings for energy efficiency and the way people actually live and work.

By Allison Arieff

Parametric technology helped architects design the signature twisted form of the 128-story Shanghai Tower.

Since the unveiling of Frank Gehry's titanium-skinned Guggenheim Museum Bilbao in 1997, we've grown accustomed to eye-popping architectural statements, whether in the complex geometry of Herzog & de Meuron's Beijing National Stadium (also known as the "Bird's Nest") or in the precarious cantilevering of Zaha Hadid's MAXXI National Museum in Rome. If it seems there's some immensely complicated system being used to engineer these gravity-defying arcs, ramps, and curves, that's because there is. But that technology, known as parametric modeling, can do much more than facilitate the fantastic creations of Gehry, Hadid, and their ilk. Increasingly, parametric design is being used not just to make buildings more visually compelling but to precisely tune nearly every aspect of their performance, from acoustics to energy efficiency. It's not as sexy an application, but it will become far more valuable to architecture and the way we live and work.

Ecotect Analysis and Revit
made by Autodesk

Rhino
made by McNeel

Grasshopper
a plug-in for Rhino

Parametric design software automatically figures out how changing any parameter of a structure will affect other physical aspects. It's more complex than the computer-aided design (CAD) software that has been the industry standard since the 1980s. That software essentially works like a digital pencil; it requires a person to move a mouse around to manipulate the lines on an architectural drawing. Today's parametric technology is more than just a drafting tool. Not only can it model a building and many of its attributes in 3-D, but it can revise a model instantly. If an architect wants to alter the pitch of a roof, for example, the walls then follow the revised roofline automatically. As Hao Ko, a design director at the architectural firm Gensler, explains, "The designer is setting the rules and parameters, with the computer doing the iterations. This gives designers more flexibility to explore designs, and we can make changes faster." It also means that architects are more willing to make changes that can ultimately make a project better.

As the technology has improved, parametric models have been able to accept more and more inputs. Architects can use the software to investigate what a building could be made of or how its natural lighting could be maximized. Or they can virtualize window dimensions and ceiling heights and the way a structure is heated and cooled. "In any project, there are a million possibilities," says architect Matthew Pierce of Perkins + Will.

Phil Bernstein, an architect and vice president at the software maker Autodesk,

Natural lighting was one of the elements that architects tried to maximize in the Bigelow Laboratory for Ocean Sciences.

believes parametric technology will help make new buildings more environmentally sustainable. (This is crucial, given that buildings account for 40 percent of the world's energy use and one-third of all carbon dioxide emissions.) The current industry standard for energy efficiency is LEED—Leadership in Energy and Environmental Design. Architects who use green features like drought-tolerant plants and efficient heating, ventilation, and air-conditioning systems can apply for LEED certification.

But critics of this approach point out that it's hard to measure the outcomes. Parametric technology might provide more precise metrics. How much energy will a building actually need? Or how much might it generate? How much water will it use? These things can be determined during the design process and rapidly optimized—you can adjust the model until you get the results you're looking for.

That was the case with Perkins + Will's design for the Bigelow Laboratory for Ocean Sciences, in East Boothbay, Maine. The firm used software called Ecotect Analysis (now owned by Autodesk) to model everything from thermal performance to daylighting—the practice of placing windows or other openings in such a way that natural light can reliably

Some of the most dramatic forms designed with parametric technology have come from Frank Gehry, whose Louis Vuitton Foundation for Creation is soon to open in Paris.

PREVIOUS SPREAD: COURTESY OF LAWRENCE WANG; COURTESY OF CHRISTOPHER BARNES; COURTESY OF FOUNDATION LOUIS VUITTON

illuminate the interior. As the architects tinkered with the design in a computer, it calculated and analyzed such properties as the building's floor area, its volume, and the required quantities of materials. They could simulate the thermal performance of different wall, roof, and window assemblies—and evaluate the performance against the cost. They could study how different types of glass would perform—not just in general but on the northeast wall at the building's exact location, under conditions suggested by long-term weather data.

Ko explains, "If you have a tall tower like that, you're studying the different degrees of rotation. It would be tedious if you had to do it manually. Using rotation as one of the parameters, you can run through the various iterations to get to the final situation."

Idiosyncratic subdivisions

For now, the most familiar built expressions of parametric design remain extreme projects like those created by Zaha Hadid Architects, a firm that is known for avoiding corners, right angles, and familiar typologies. We see a similar avoidance of corners in the astounding 19,000 molded glass-reinforced concrete pieces and 3,500 custom curved glass panels that make up Frank Gehry's design for the Louis Vuitton Foundation for Creation, a $100-million-plus museum scheduled to open in Paris next year.

Even so, many architects (and their clients) are increasingly asserting that gesture and complexity for their own sake are not enough. Accordingly, the building industry is becoming more knowledgeable about improving a structure's function. Architecture graduates arrive at firms armed with expertise in parametric tools such as Revit, Grasshopper, and Rhino; they may never have designed without the help of computers, and parametric modeling is familiar to them. Among builders, engineers, and architects, the adoption of advanced digital tools for what's known as building information modeling surged from 28 percent in 2007 to 49 percent in 2009 and 71 percent in 2012.

The signature curves in Beijing's Olympic stadium arose from a complex geometry that demanded computer modeling.

SEAN GALLUP/GETTY IMAGES

The benefits of parametric technology can similarly be seen in Gensler's soon-to-be-completed Shanghai Tower, which at 630 meters will be the second-tallest tower in the world and the tallest in China. Its twisting, curved form was an aesthetic choice, to be sure, but by plugging that geometry into a modeling tool known as Grasshopper, the designers were able to tweak the shape to minimize the force of winds on the façade. As

And while such technology is useful for formally complex buildings, even simpler forms should benefit from it. Architects Nataly Gattegno and Jason Kelly Johnson of Future Cities Lab believe parametric design can change how we think about floor plans of houses or grid patterns of planned communities. "Do these houses all have to be the same?" Gattegno asks. Parametric modeling "could open up all kinds of possibilities of what a house

could be." Mass-produced housing might become less cookie-cutter, more idiosyncratic, and more economical and energy efficient.

Similarly, the technology could reshape urban planning. Just as it can create a detailed representation of a wall, it can model an entire neighborhood to determine the optimal size and shape of the various structures in it, says Autodesk's Bernstein. Awkwardly scaled McMansions might be rethought to make more efficient use of lots, building materials, and energy.

Parametric modeling can even take human proportions and movement into account. A company called AnyBody Technology, for example, does full-body physical simulations for the design of cockpits or workspaces. The company has begun collaborating on R&D with architects so that a parametric model can be used to simulate a body walking through a given space. Eventually, architects could design, say, a nursing home in a way that optimized walking distances or ergonomics.

Of course, models are still mere simulations. And one thing that this modeling can't automatically account for—yet, anyway—is human behavior. Bernstein told me that when Autodesk built its LEED-certified headquarters, its designers "energy-modeled the hell out of it" in parametric software only to find out that the building used 30 percent more energy than they had anticipated. Why? Among other things, after the lights automatically went off at 6:30 P.M., cleaning crews turned them back on and didn't shut them off again.

Allison Arieff is a content strategist for SPUR, an urban planning and policy think tank in San Francisco, and a contributing columnist at the New York Times.

ISTVAN BANYAI

Romancing the Phone

Love and sex in the age of social media and mobile communication.

By C.J. Pascoe

Boy meets girl; they grow up and fall in love. But technology interferes and threatens to destroy their blissful coupledom. The destructive potential of communication technologies is at the heart of Stephanie Jones's self-published romance novel *Dreams and Misunderstandings*. Two childhood sweethearts, Rick and Jessie, use text messages, phone calls, and e-mail to manage the distance between them as Jessie attends college on the East Coast of the

United States and Rick moves between Great Britain and the American West. Shortly before a summer reunion, their technological ties fail when Jessie is hospitalized after a traumatic attack. During her recovery, she loses access to her mobile phone, computer, and e-mail account. As a result, the lovers do not reunite and spend years apart, both thinking they have been deserted.

Jones blames digital innovations for the misunderstandings that prevent Rick and Jessie's reunion. It's no surprise this theme runs through a romance novel: it reflects a wider cultural fear that these technologies impede rather than strengthen human connection. One of the Internet's earliest boosters, MIT professor Sherry Turkle, makes similar claims in her most recent book, *Alone Together: Why We Expect More of Technology and Less from Each Other*. She argues that despite their potential, communication technologies are threatening human relationships, especially intimate ones, because they offer "substitutes for connecting with each other face-to-face."

Dreams and Misunderstandings
Stephanie Jones
AuthorHouse UK, 2012

Alone Together: Why We Expect More of Technology and Less from Each Other
Sherry Turkle
Basic Books, 2011

The End of Sex: How Hookup Culture Is Leaving a Generation Unhappy, Sexually Unfulfilled, and Confused About Intimacy
Donna Freitas
Basic Books, 2013

If the technology is not fraying or undermining existing relationships, stories abound of how it is creating false or destructive ones among young people who send each other sexually explicit cell-phone photos or "catfish," luring the credulous into online relationships with fabricated personalities. In her recent book about hookup culture, *The End of Sex*, Donna Freitas indicts mobile technologies for the ease with which they allow the hookup to happen.

It is true that communication technologies have been reshaping love, romance, and sex throughout the 2000s. The Internet, sociologists Michael Rosenfeld and Reuben Thomas have found, is now the third most common way to find a partner, after meeting through friends or in bars, restaurants, and other public places. Twenty-two percent of heterosexual couples now meet online. In many ways, the Internet has replaced families, churches, schools, neighborhoods, civic groups, and workplaces as a venue for finding romance. It has become especially important for those who have a "thin market" of potential romantic partners—middle-aged straight people, gays and lesbians of all ages, the elderly, and the geographically isolated. But even for those who are not isolated from current or potential partners, cell phones, social-network sites, and similar forms of communication now often play a central role in the formation, maintenance, and dissolution of intimate relationships.

While these developments are significant, fears about what they mean do not accurately reflect the complexity of how the technology is really used. This is not surprising: concerns about technology as a threat to the social order, particularly in matters of sexuality and intimacy, go back much further than Internet dating and cell phones. From the boxcar (critics worried that it could transport those of loose moral character from town to town) to the automobile (which gave young people a private space for sexual activity) to reproductive technologies like in vitro fertilization, technological innovations that affect intimate life have always prompted angst. Often, these fears have resulted in what sociologists call a "moral panic"—an episode of exaggerated public anxiety over a perceived threat to social order.

Moral panic is an appropriate description for the fears expressed by Jones, Turkle, and Freitas about the role of technology in romantic relationships. Rather than driving people apart, technology-mediated communication is likely to have a "hyperpersonal effect," communications professor Joseph Walther has found. That is, it allows people to be more intimate with one another—sometimes more intimate than would be sustainable face to face. "John," a college freshman in Chicago whom I interviewed for research that I published in a 2009 book, *Hanging Out, Messing Around and Geeking Out: Kids Living and Learning with New Media*, highlights this paradox. He asks, "What happens after you've had a great online flirtatious chat ... and then the conversation sucks in person?"

In the initial getting-to-know-you phase of a relationship, the asynchronous nature of written communication—texts, e-mails, and messages or comments on dating or social-network sites, as opposed to phone calls or video chatting—allows people to interact more continuously and to save face in potentially vulnerable situations. As people flirt and get to know each other this way, they can plan, edit, and reflect upon flirtatious messages before sending them. As John says of this type of communication, "I can think about things more. You can deliberate and answer however you want."

Technology can allow people to be more intimate with one another than would be sustainable face to face.

As couples move into committed relationships, they use these communication technologies to maintain a digital togetherness regardless of their physical distance. With technologies like mobile phones and social-network sites, couples need never be truly apart. Often, this strengthens intimate relationships: in a study on couples' use of technology in romantic relationships, Borae Jin and Jorge Peña found that couples who are in greater cell-phone contact exhibit less uncertainty about their relationships and higher levels of commitment. This type of communication becomes a form of "relationship work" in which couples trade digital objects of affection such as text messages or comments on online photos. As "Champ," a 19-year-old in New York, told one of my collaborators on *Hanging Out, Messing Around and Geeking Out* about his relationship with his girlfriend, "You send a little text message—'Oh I'm thinking of you,' or something like that—while she's working … Three times out of the day, you probably send little comments."

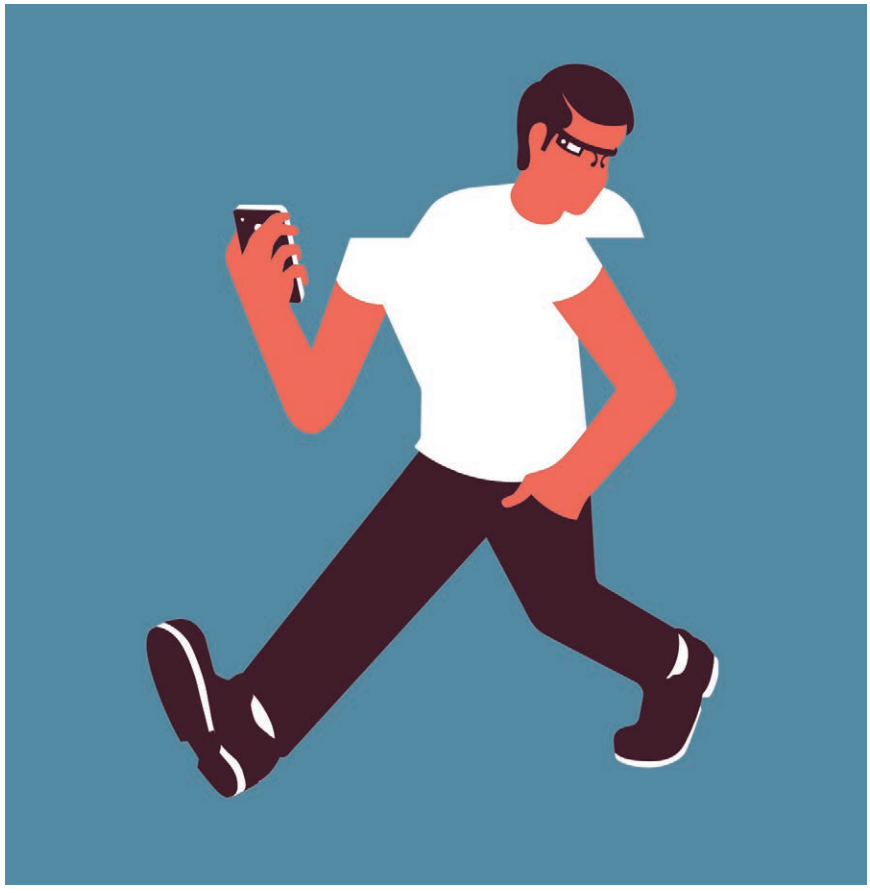
To be sure, some of today's fears are based on the perfectly accurate observation that communication technologies don't always lend themselves to constructive relationship work. The public nature of Facebook posts, for example, appears to promote jealousy and decrease intimacy. When the anthropologist Ilana Gershon interviewed college students about their romantic lives, several told her that Facebook threatens their relationships. As one of her interviewees, "Cole," said: "There is so much drama. It's adding another stress."

But overall, the research by Gershon and others indicates that people often have a shared understanding of how and when technology should be used in romantic relationships. In fact, in no small part because people primarily use social media to express connection, they do not like using it to end relationships. Only 25 percent of social-media users claim that they would use technology to discuss serious issues with their partners, and a very small number reported that they would terminate their relationship that way. When Gershon asked students at her university to describe a "bad" breakup, they immediately discussed any breakup that was initiated via social media. In *Hanging Out, Messing Around and Geeking Out*, "Grady," a 16-year-old high-school student, said that breaking up by text or social network was especially "disrespectful," because "they can't say anything back or anything."

Research indicates that people often have a shared understanding of how and when technology should be used in romantic relationships.

Given the nuanced understanding people have of the role technology plays in their relationships, the idea of new media as a dehumanizing force is overblown. What research tells us is that technology can't make relationships, nor can it ruin them. But technology has changed relationships. It can facilitate the development of emotional intimacy. It can lubricate sexual liaisons with strangers. It can also increase the risk of deception among intimates. All this may put an extra burden on relationships, requiring that couples do relationship work in offline as well as online spaces. Had Rick and Jessie mastered those demands, they might have been spared the years apart.

C.J. Pascoe is an assistant professor at the University of Oregon, where she teaches courses on sexuality, gender, and youth. She is the author of Dude, You're a Fag: Masculinity and Sexuality in High School *(2007).*



MIGUEL MONTANER

The Paradox of Wearable Technologies

Can devices like Google Glass augment our activities without distracting us from the physical world?

By Don Norman

Ever talk to someone at a party or conference reception only to discover that he or she is constantly scanning the room, looking this way and that, perhaps finding you boring, perhaps looking for someone more important? Doesn't the person realize that you notice?

Welcome to the new world of wearable computers, where we will tread uneasily as we risk continual distraction, continual diversion of attention, and continual blank stares in hopes of achieving focused attention, continual enhancement, and better interaction, understanding, and retention. Google's latest hardware toy, Glass, which has received a lot of attention, is only the beginning of this challenge.

Google Glass

Thinking, Fast and Slow
by Daniel Kahneman
Farrar, Straus, and Giroux, 2011

Actually, it isn't the beginning—this stuff has been around for over a decade. In my former roles as a cognitive scientist and vice president of technology at Apple, and now as a management consultant in product design, I visit research laboratories at companies and universities all over the world. I've experienced many of these devices. I've worn virtual-reality goggles that had me wandering through complex computerized mazes, rooms, and city streets, as well as augmented realities where the real world was overlaid with information.

And yes, I've worn Google Glass. Unlike "immersive" displays that capture your full attention, Glass is deliberately designed to be inconspicuous and nondistracting. The display is only in the upper right of the visual field, the goal being to avoid diverting the user's attention and to provide relevant supplementary information only when needed.

Even so, the risk of distracting the user is significant. And once Google allows third-party developers to provide applications, it loses control over the ways in which these will be used. Sebastian Thrun, who was in charge of Google's experimental projects when Glass was conceived, told me that while he was on the project, he insisted that Glass provide only limited e-mail functionality, not a full e-mail system. Well, now that outside developers have their hands on it, guess what one of the first things they did with it was? Yup, full e-mail.

It's a great myth that people can multitask without any loss in the quality of their work. Numerous psychology experiments show that when two relatively complex tasks are done at the same time, performance deteriorates measurably. Some of these experiments were done by me, back when I was a practicing cognitive scientist. David Strayer, whose research group at the University of Utah has studied these issues for decades, has shown that hands-free phones are just as distracting as handheld ones, and using one while driving is just as bad as driving while drunk.

Even pairs of tasks as simple as walking and talking can show performance decrement: it happens to me all the time. While I am thinking or deep in conversation on my morning walk, I often stop walking when I get to difficult and profound thoughts. The stopping is subconscious, perceived only when my conscious mind breaks its concentration to notice that the walking has halted. Psychologist (and Nobel laureate) Danny Kahneman notes in his book *Thinking, Fast and Slow* that he discovered he couldn't think at all when he walked too fast. He had to slow down to allow new thoughts.

If performing tasks simultaneously is so deleterious, why do people maintain that they can do it without any deterioration? Well, it is for somewhat the same reason that drunk drivers think they can drive safely: monitoring our own performance is yet another task, and it suffers. The impairment in mental skills makes it difficult to notice the impairment.

So while the supplementary, just-in-time information provided by wearable computers seems wonderful, as we come to rely upon it more and more, we can lose engagement with the real world. Sure, it is nice to be reminded of people's names and perhaps their daughter's recent skiing accident, but while I am being reminded, I am no longer there—I am somewhere in ether space, being told what is happening.

Years ago, I wrote a piece called "I Go to a Sixth Grade Play" in which I discussed the parents so anxiously video-recording their children in the play that they didn't experience the event until the next day. Detached engagement is not the same thing as full engagement; it lacks the emotional dimension.

There is a flip side to this argument, however. It is that when implemented and used mindfully, wearable technology can enhance our abilities significantly. Thad Starner, a wearable-computer champion who has worn these devices for almost a quarter-century and was a technical advisor to Google Glass, sent me comments on an early draft of this article. "I am very bad at multitasking," he said, noting that when he attends a lecture, "[by] putting the physical focus of the display at the depth of the blackboard and having a fast text entry method, I could (suddenly) both pay attention and take good notes." He did far better than he could with paper and pencil, which forced his attention to shift from notebook to blackboard. He then reminded me of a conversation we had on this topic in 2002. I didn't remember the conversation, so he described the interaction, reminding me of both his comments and my responses.

Much of what is being done with wearable devices is happening simply because it can be done.

How can Starner remember the details of a conversation from more than 10 years ago? He takes notes during his conversations, one hand in his pocket typing away on a special keyboard. The result is that during any interaction, he is far more focused and attentive than many of my non-computer-wearing colleagues: the act of taking notes forces him to concentrate upon the content of the interaction. Moreover, he has records of his interactions, allowing him to review what took place—which is how he "remembered" our decade-old conversation. (See the Q&A with Starner in our July/August 2013 issue, and "You Will Want Google Goggles," July/August 2012.)

Without the right approach, the continual distraction of multiple tasks exerts a toll. It takes time to switch tasks, to get back what attention theorists call "situation awareness." Interruptions disrupt performance, and even a voluntary switching of attention from one task to another is an interruption of the task being left behind.

Furthermore, it will be difficult to resist the temptation of using powerful technology that guides us with useful side information, suggestions, and even commands. Sure, other people will be able to see that we are being assisted, but they won't know by whom, just as we will be able to tell that they are being assisted, and we won't know by whom.

Eventually we will be able to eavesdrop on both our own internal states and those of others. Tiny sensors and clever software will infer emotional and mental states. Worse, the inferences will often be wrong: many factors could cause a person's pulse rate to go up or skin conductance to change, but technologists are apt to focus upon a simple, single interpretation.

Is this what we want? People staring blankly at the real world as their virtual minders tell them what is happening? We are entering unknown territory, and much of what is being done is happening simply because it can be done.

In the end, either wearable technologies will be able to augment our experiences and focus our attention on a current task and the people with whom we are interacting, or they'll distract us—diverting our attention through tasty morsels of information that are irrelevant to the current activity.

When technologies are used to supplement our activities, when the additional information being provided is of direct relevance, our attention can become more highly focused and our understanding and retention enhanced. When the additional information is off target, no matter how enticing it is, that's the distracting and disruptive side.

I like to look on the positive side of technology. I even wrote a book, *Things That Make Us Smart*, about the power of artifacts to enhance human abilities. I am fully dependent upon modern technologies, because they make me more powerful, not less. By taking away the dreary, unessential parts of life, I can concentrate upon the important, human aspects. I can direct high-level activities and strategies and maintain friendships with people all over the world. That's the focused side. On the other hand, I spend many hours each day simply keeping up with people who continually contact me, almost always with interesting comments, news, and invitations, but nonetheless exceeding my ability to cope and distracting me from my primary activities. Yes, I welcome these distractions because they are a pleasant diversion from the hard work of writing, thinking, and decision-making, but procrastination, even though it's enjoyable, does not help get the work done. I already had to hire a human assistant to help keep me focused. Will the continual stream of messages from wearable devices prove to be irresistible, diverting me from my work, or will they amplify my abilities?

A standard response is to put the burden on the individual: it is our responsibility to use technology responsibly. I agree in theory, but not in practice. I know all too well the temptations of distraction—all that fascinating news, all those friends who send me status reports and wish me to respond with my own. I find it easy to succumb—anything to avoid the difficult, dreary concentration required to accomplish anything of value. I've often had to unplug my computer from the Internet to complete my work. The providers of these technologies must share the burden of responsible design.

Can wearable devices be helpful? Absolutely. But they can also be horrid. It all depends upon whether we use them to focus and augment our activities or to distract. It is up to us, and up to those who create these new wearable wonders, to decide which it is to be.

Don Norman is a cognitive science professor (UC San Diego, Northwestern) turned executive (Apple vice president) turned designer (IDEO Fellow), and author of 20 books, including Living with Complexity *and* The Design of Everyday Things. *He can be found at jnd.org.*

Demo

1 Michael McAlpine is a nanomaterials scientist at Princeton University.

Cyborg Parts

Princeton researchers use a 3-D printer to build a bionic ear with integrated electronics.

By Susan Young
Photographs by Ken Richardson

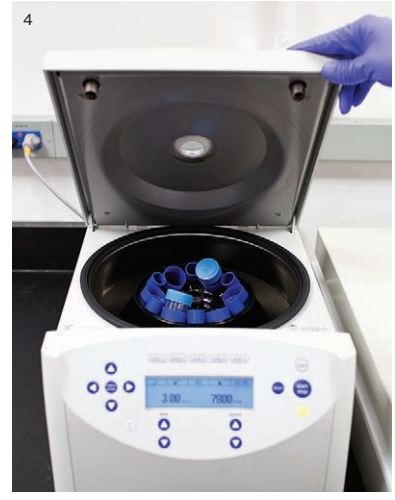
Lab-made organs could do more than just serve as ready options for patients in need: with the right blend of biology and materials science, they might even be able endow people with superhuman abilities.

That's what researchers at Princeton University see as the future of tissue engineering, and they believe 3-D printing is the way there. Michael McAlpine and members of his lab recently reported that a 3-D printer could build a bionic ear capable of detecting frequencies a million times higher than the normal range of hearing.

The ear demonstrates how 3-D printing can seamlessly bring together electronics and biological tissues. Normally, these materials don't play well together—one is rigid and fractures easily, while the other is soft and flexible. But with 3-D printing, the two can be fabri-

2 Cartilage-forming cells from a cow are grown in an incubator.

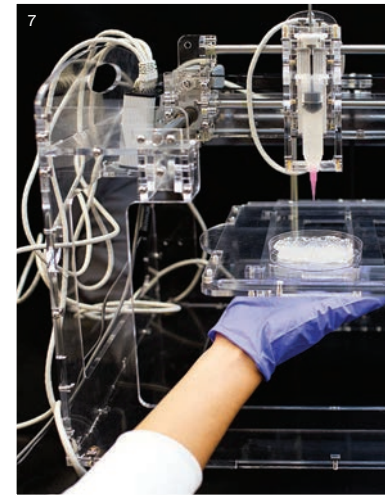
3 Graduate student Manu Mannoor checks to see if enough cells have grown.



4 The cells are centrifuged to collect them in the bottom of a tube.

5 The small white disk at the bottom of the tube is a pellet of cells.

6 The bovine cells, now mixed into a gummy matrix, are loaded into a syringe for printing.



7 A 3-D printer has been modified for building bionic tissues.

8 The printer ejects droplets of different materials to build up a bionic ear, layer by layer.

9 Over the next 10 weeks, the ear will be submerged in liquid nutrients. The cells will build up cartilage, which will surround the signal-receiving silver electrode coil.

cated together, says McAlpine. "It's a way you can naturally intertwine everything together into a three-dimensional format," he says. This could help researchers make body tissues with integrated devices that can monitor health, or even build cyborg organs that augment conventional senses.

The team started with an ear because the shape is difficult to re-create with traditional tissue engineering. Also, much of an ear is cartilage, which lacks blood vessels—structures that elude tissue engineers (for now).

To build the bionic organ, the printer is guided by a computer model of an ear to which the team added the model of an internal electrode coil. Layer by layer, the machine alternates among three "inks": a mix of bovine cartilage-forming cells suspended in a thick goo of hydrogel; silicone, to encase the cochlea-shaped electrodes; and a suspension of silver nanoparticles. The silver nanoparticles are packed tightly so that the cochlea-shaped coil can conduct electricity. "It acts as a metal, but because they are nanoparticles, you can print them in a way that you couldn't normally print a metal," McAlpine says.

Printing takes about four hours. Then the ear is bathed in a nutrient-rich broth so that the cells can grow, produce collagen and other molecules, and replace their original surroundings with cartilage.

With its fully embedded coil, the bionic ear can detect and transmit radio signals—but not sound waves. McAlpine says that functionality could be added to future models by integrating piezoelectric materials, which convert mechanical energy into electrical energy. One day these devices could help a person hear through the same mechanism used to connect cochlear implants, or perhaps provide a sixth sense of electromagnetic reception.

Next McAlpine wants to expand the range of objects a 3-D printer can produce. "There are significant challenges," he says. But with higher-resolution printers, he thinks, his team will be able to introduce higher-end electronics.

Beyond enabling biological tissues to incorporate materials with exceptional properties, 3-D printing could address a tissue-engineering challenge: how to grow organs with blood vessels. "Vasculature networks have an incredibly complicated geometry," McAlpine says. Such a breakthrough would be key to printing organs that contain blood vessels, such as livers, kidneys, and hearts. T

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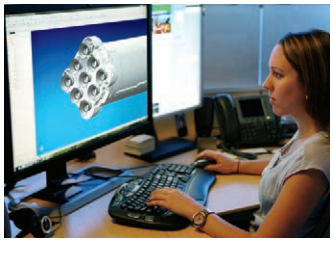

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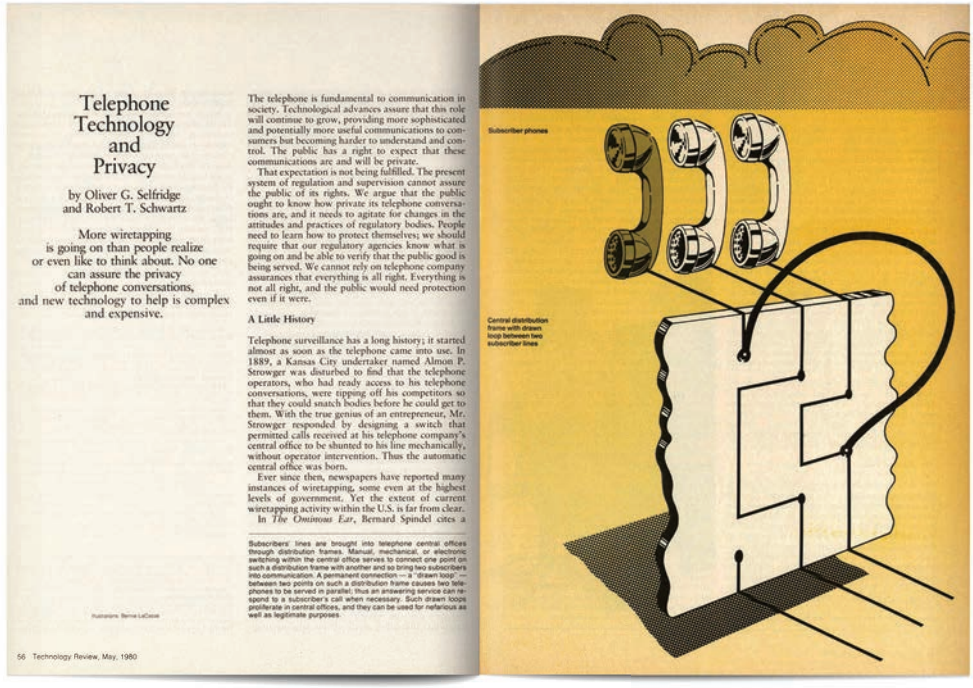

Telephone Technology and Privacy

by Oliver G. Selfridge and Robert T. Schwartz

More wiretapping is going on than people realize or even like to think about. No one can assure the privacy of telephone conversations, and new technology to help is complex and expensive.

The telephone is fundamental to communication in society. Technological advances assure that this role will continue to grow, providing more sophisticated and potentially more useful communications to consumers but becoming harder to understand and control. The public has a right to expect that these communications are and will be private.

That expectation is not being fulfilled. The present system of regulation and supervision cannot assure the public of its rights. We argue that the public ought to know how private its telephone conversations are, and it needs to agitate for changes in the attitudes and practices of regulatory bodies. People need to learn how to protect themselves; we should require that our regulatory agencies know what is going on and be able to verify that the public good is being served. We cannot rely on telephone company assurances that everything is all right. Everything is not all right, and the public would need protection even if it were.

A Little History

Telephone surveillance has a long history; it started almost as soon as the telephone came into use. In 1889, a Kansas City undertaker named Almon P. Strowger was disturbed to find that the telephone operators, who had ready access to his telephone conversations, were tipping off his competitors so that they could snatch bodies before he could get to them. With the true genius of an entrepreneur, Mr. Strowger responded by designing a switch that permitted calls received at his telephone company's central office to be shunted to his line mechanically, without operator intervention. Thus the automatic central office was born.

Ever since then, newspapers have reported many instances of wiretapping, some even at the highest levels of government. Yet the extent of current wiretapping activity within the U.S. is far from clear. In *The Ominous Ear*, Bernard Spindel cites a

Subscribers' lines are brought into telephone central offices through distribution frames. Manual, mechanical, or electronic switching within the central office serves to connect one point on such a distribution frame with another and so bring two subscribers into communication. A permanent connection — a "drawn loop" — between two points on such a distribution frame causes two telephones to be served in parallel; thus an answering service can respond to a subscriber's call when necessary. Such drawn loops proliferate in central offices, and they can be used for nefarious as well as legitimate purposes.

Illustrations: Bernie LaCasse

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Subscriber phones

Central distribution frame with drawn loop between two subscriber lines

Who's Listening to Your Calls?

"More wiretapping is going on than people realize or even like to think about," warned a 1980 article on surveillance.

The telephone is fundamental to communication in society. The public has a right to expect that these communications are and will be private. That expectation is not being fulfilled. We cannot rely on telephone company assurances that everything is all right. Everything is not all right, and the public would need protection even if it were.

Perhaps 50 percent of U.S. telephones are now served by electronic switching systems (ESS), in which messages are transmitted electronically under computer control. Soon after the first electronic switching system exchanges went into service in 1966, we discovered that the 'test board' typically associated with an ESS exchange could become a powerful tool to an eavesdropper.

The *Wall Street Journal*, for example (October 5, 1973), quoted a New Jersey assistant prosecutor: 'We use a system where you can effectively sit in your home and monitor any phone in the country. You'll hear everything that transpires over that number.'

The general effect of this new technology is to widen the gap between the communications elite and the public. Most people can easily understand a cord patchboard, in which an operator sits and plugs people's wires in where lights shine. But few understand a computer program that does the same thing in vastly more complex and comprehensive ways.

With such advances must come an increasingly alert public. People must abandon the attitude that 'it may be true, but it doesn't concern me, and I don't care if my phone is tapped.' That is said by people who are fairly, if perhaps falsely, sure that their telephones are not tapped. If they discovered that their conversations were being overheard and transcribed, they would almost certainly be outraged."

Excerpted from "Telephone Technology and Privacy," by Oliver G. Selfridge and Robert T. Schwartz, in the May 1980 issue of Technology Review.

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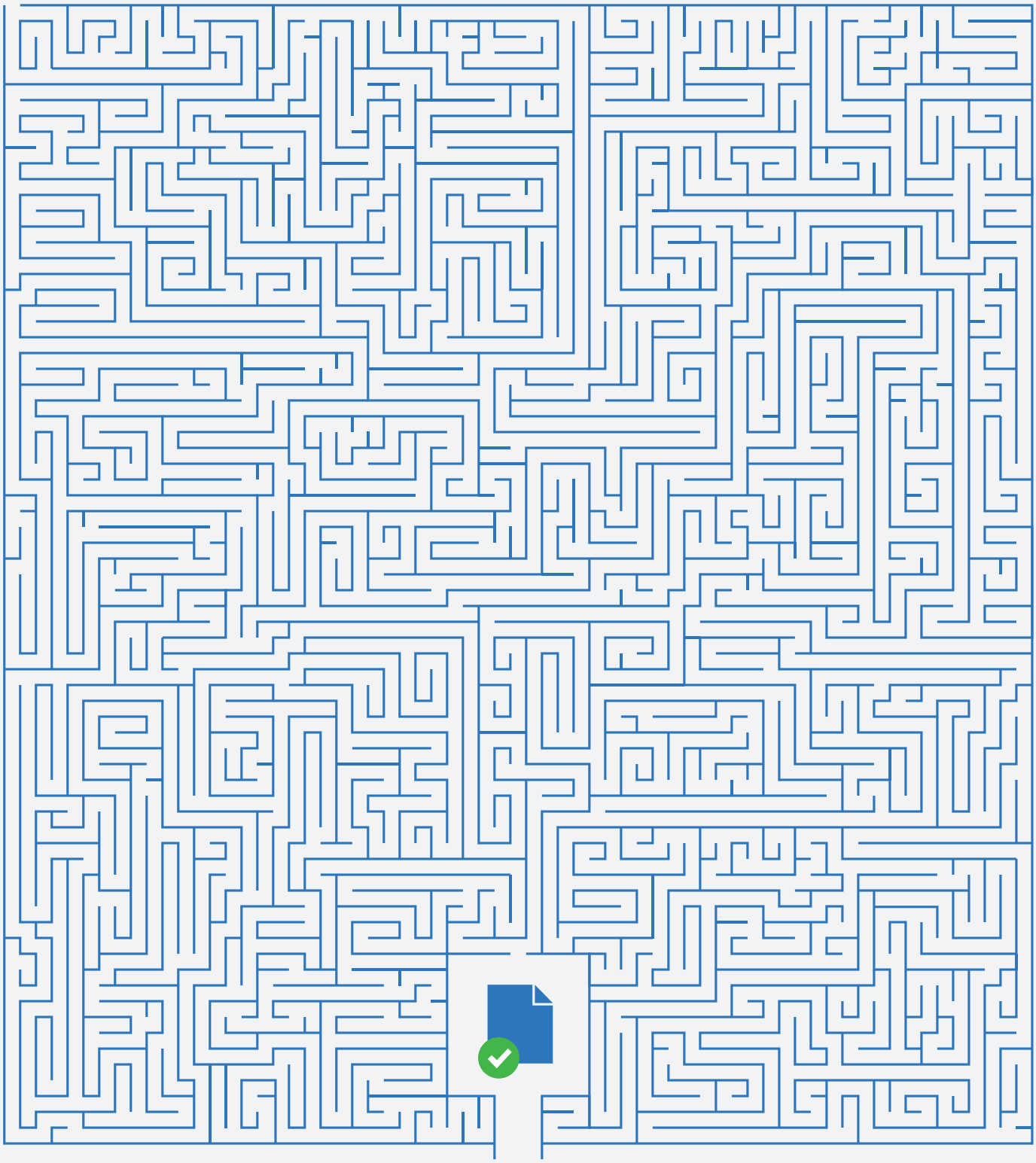

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